[illegible]

ERRATA.

Bottom of page 17; instead of "Ampere = turns" read "Ampere – turns."

Ques. 244, page 92; instead of "$\frac{4}{00}$" read "$\frac{4}{100}$"

Ques. 264, page 106; instead of "$\dfrac{Ra \times Rb \times Rc}{Ra \times Rb + Rb \times Rc + Rc \times Ra}$",

read "$\dfrac{Ra \times Rb \times Rc}{(Ra \times Rb) + (Rb \times Rc) + (Rc \times Ra)}$",

Ques. 517, page 200; instead of "precisely ½ ohm" read "about 244 ohms."

Ques. 517, page 200; instead of "1 ohm" read "450 ohms."

THE

Electrical Catechism

533 PLAIN ANSWERS
TO 533 PRACTICAL
QUESTIONS ABOUT
ELECTRICAL APPARATUS

COMPILED FROM THE REGULAR ISSUES OF

POWER

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PREFACE.

In the preparation of the subject matter of this book it has been the aim of the author to discuss only such branches of electrical work as may be considered to come within the range of the average central station or isolated plant engineer. On this account the endeavor has not been to cover the entire electrical field, but rather to make the treatment of principles and practice in what might be termed the "heavier" branches of electrical engineering more exhaustive than is usual in a work of this kind.

It goes without saying that no originality is claimed for the subject matter; didactic productions cannot be original in the strict literary sense; but a strong effort has been made to present the expository matter in logical sequence and in clear, every-day phraseology.

Parts of the matter here presented have appeared in serial form in the pages of *Power;* such portions have been carefully revised to eliminate typographical errors and to bring them up to date wherever this might be required.

THE AUTHOR.

NEW YORK, March 25, 1902.

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ELECTRICAL CATECHISM.

CHAPTER I.

Q. 1—How long has the existence of electricity been known?

A.—It is mentioned in a treatise on gems, written about 600 B. C., by a Greek author named Theophrastus.

Q. 2—What statement does this writer make?

A.—That a piece of amber when rubbed briskly with a piece of silk possesses the power of attracting to itself light bodies, such as dust or pieces of paper.

Q. 3—What has this to do with electricity?

A.—When the amber manifests the power of attraction mentioned, it is said to be electrified, or charged with electricity.

Q. 4—What is the name given to this kind of electricity?

A.—Frictional or static electricity.

Q. 5—Why is it called static electricity?

A.—Because it is at rest as distinguished from active currents of electricity.

Q. 6—Can a body be charged with electricity except by friction?

A.—Yes; by contact with a body already electrified.

Q. 7—How does electrification by contact take place?

A.—Electricity is transferred from the body originally electrified to the body touched.

Q. 8—What is this transfer of electricity called?

A.—It is called a discharge, with reference to the body originally electrified.

Q. 9—What is meant by "active currents of electricity"?

A.—The continuous discharge or passage of electricity, supplied to a body as fast as it can be taken away. Fig. 1 shows a pump, *A*, drawing water from a tank, *B*, and forcing it through a line of pipe, *C*, which discharges into the tank. The amount delivered into the tank must be evidently equal to the amount taken out by the pump. This is similar to the flow of a current of electricity.

Q. 10—How may a continuous current of electricity be produced?

A.—The most common means are voltaic cells, and dynamos.

Q. 11—What is a voltaic cell?

A.—A glass jar containing some water having added to it a little sulphuric acid, together with two clean strips, one of zinc, *Z*, and one of copper, *C*, as in Fig. 2, forms a simple voltaic cell.

Q. 12—With the cell, as shown, will any current be produced?

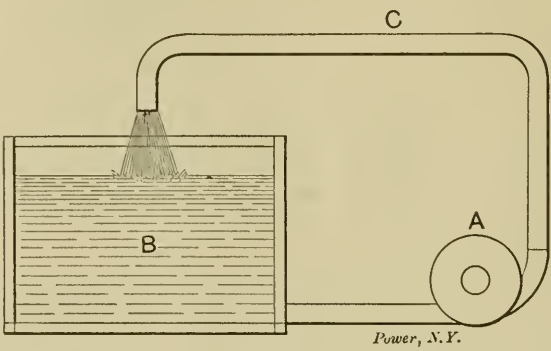


Fig. 1

A.—No. The cell provides the E.M.F. or pressure which causes electricity to flow, but in order to obtain an actual flow it is necessary to connect the two plates by means of a wire, as shown in Fig. 3.

Q. 13—What purpose does this wire serve?

A.—It completes the path for the current to flow through.

Q. 14—What arrangement of a pump can be made to give similar results with water?

A.—Place a pump in a tank of water, as in Fig. 4. If rotated,

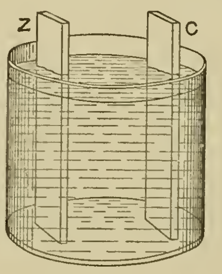


FIG. 2.

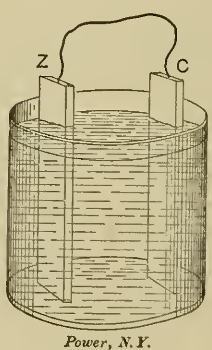


FIG. 3.

it will simply churn the water up. If, however, the piping shown in Fig. 5 is added, there will be a continuous flow of water

through the pipe. This illustration is not absolutely correct, because the return pipe need not touch the water in the tank, while the wire must touch both pieces, *Z* and *C*. These pieces are called electrodes, the zinc being the negative electrode and the copper the positive electrode. The wire connecting the two is called a conductor, because it "conducts" the current.

Q. 15—Will not any material conduct it?

A.—No. Metals, acids and carbon are conductors of electricity, and most other substances are non-conductors, or "insulators," practically.

Q. 16—Are insulators used in electrical work?

A.—Yes; to prevent contact between a conductor and some outside metallic substance, which would cause the current to "leak" away from its conductor.

Q. 17—How does a current flow in a conductor?

A.—From the positive to the negative electrode of the battery, or other source of electricity.

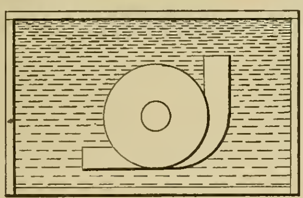


FIG. 4.

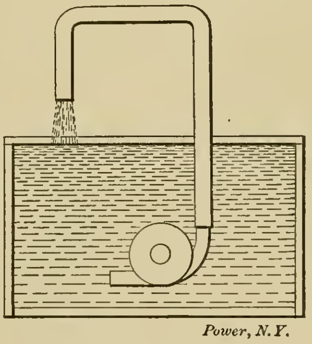


FIG. 5.

Q. 18—In which direction does the current flow in the cell?

A.—From the zinc (negative electrode) to the copper strip (positive electrode).

Q. 19—Will the cell furnish electricity indefinitely?

A.—No; the zinc strip will be observed to waste away. It is dissolved by the acid and parts with its latent energy while its atoms combine with the acid. This energy is expanded in forcing the electricity through the acid to the copper strip, through the copper strip and the wire back to the zinc strip. When the zinc is consumed no more current will be produced.

Q. 20—Is an electric current visible?

A.—No; its existence is shown by its effects.

Q. 21—What are some of the effects produced by an electric current?

A.—A current flowing through a wire will heat it, and if the wire is thin and the current strong, this heating will be very apparent. If the current flows through water or other liquids it will decompose them. If the wire through which the current flows be led near a magnetic needle it will cause it to turn aside or deflect. If the current passes through the air across a break in a conductor a spark is visible across the gap.

Q. 22—Describe an experiment that shows the deflection of a needle under the influence of a current?

A.—Take a compass needle; it will point north and south, as shown in Fig. 6. Now, hold a wire in which a current flows parallel to the direction of the needle. The needle will be deflected so that it stands east and west, or at right angles to its previous position.

Q. 23—In which direction will the needle be deflected?

A.—If the current flows, as shown by the straight arrow in the figure, the pole marked, *N,* will be twisted toward the east, as shown by the curved arrows. If the current were reversed, the pole, *N*, would deflect toward the west. If the current were from north to south, as shown, but the wire below the needle, the pole, *N*, would move toward the west. If the wire were below the needle and the current reversed, the needle would deflect toward the east. Table I. shows this:

TABLE I.

Direction of Current.	Position of Wire with Regard to Needle.	Pole *N* is Deflected Toward.
North to South	Above	East
North to South	Below	West
South to North	Above	West
South to North	Below	East

Q. 24—Describe an experiment that shows the effect of a current in decomposing a liquid through which it passes.

A.—Carry two wires from the electrodes of a voltaic cell to a small cup containing dilute sulphuric acid, as in Fig. 7. Place

the free ends in the cup containing the solution, taking care that these ends do not touch each other. It will be noticed after a time that the end of one wire becomes covered with bubbles, which collect and rise to the surface, and that this is the wire connected to

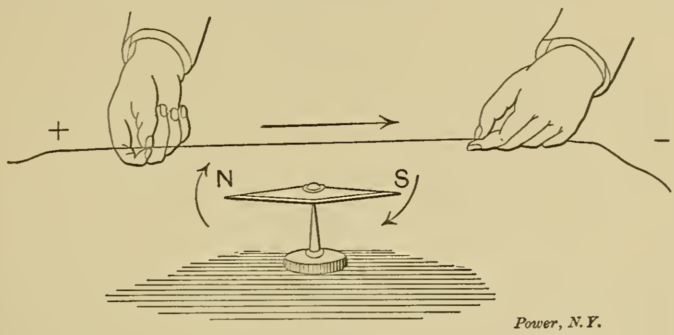


FIG. 6.

the zinc or negative electrode of the cell. The other wire becomes cleaner and brighter, as if the acid were dissolving it. This is really the case, as will be proved by the sulphuric acid taking on a blue tinge. If the action be allowed to continue for a long enough time, the negative terminal will be found covered with a brown deposit, which is pure copper, and the solution in the small cup will be found to have changed from sulphuric acid to sulphate of copper.

Q. 25—What determines the amount of copper dissolved from one electrode and deposited on the other?

A.—The rate of flow of the current.

Q. 26—What is meant by the rate of flow?

A.—The strength of the current passing through a conductor. The unit of the rate of flow is called an ampere.

Q. 27.—What determines the value of the ampere?

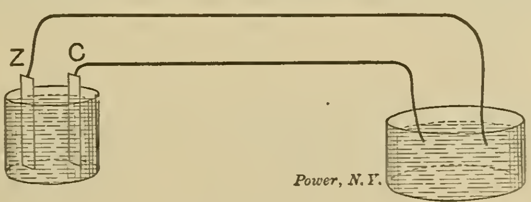


FIG. 7.

A.—It is the unvarying rate which will deposit 0.001118 of a gramme * of silver per second, when the current is forced through

*One ounce contains 28.3495 grammes. 0.001118 gramme = $\frac{1}{20050}$ ounce, scant.

a solution of nitrate of silver, from one silver plate to another.

Q. 28—What is the ampere similar to in the flow of water?

A.—To the cross-sectional area of a body of water flowing in a pipe. The volume of water (cubic inches or feet) is analogous to *coulombs* in electrical work. Amperes × seconds of time = coulombs. The symbol is *Q*, denoting quantity.

Q. 29—Does the wire or other conductor through which the current flows oppose the passage of the current?

A.—Yes; this opposition is called resistance.

Q. 30—Give an analogue to the resistance of conductors to the passage of a current of electricity.

A.—When water flows in pipes or conduits it meets with a certain resistance, which is known as friction. This corresponds roughly with the electrical resistance of conductors.

Q. 31—What determines the resistance of an electrical conductor?

A.—Its material, area and length. Different materials, even if all of one size, offer different resistances. If a material of certain area and length has a certain resistance, doubling its length will double its resistance. If the length remains constant, the larger the area, the smaller the resistance.

Q. 32—How does the area affect the resistance?

A.—In somewhat the same way that the area of a pipe affects its resistance to the flow of water. If a wire of a certain area has a certain resistance per foot of length, a wire of twice the area will have half the resistance, because it is the same as two wires of the smaller size, side by side, giving two paths to the current instead of one.

Q. 33—Then the resistance per foot of a given material is less the greater its area?

A.—Yes.

Q. 34—What units is resistance measured in?

A.—Ohms. One ohm is the resistance of a column of mercury, one millimeter (0.03937 inch) square and 1.063 meters (41.85 inches) high, at the temperature of melting ice (32 degrees Fahr.)

Q. 35—Why does current flow from a battery or a dynamo?

A.—The battery generates electrical pressure, or E.M.F. by the decomposition of its elements. A dynamo generates this pressure

by induction, which will be explained later. This E.M.F. causes current to flow through a wire just as steam pressure forces steam through a pipe.

Q. 36—Is electrical pressure measured in pounds?

A.—No; the unit is the volt.

Q. 37—What fixes the value of a volt?

A.—The other two units, ampere and ohm. One volt is that pressure which will cause a current of 1 ampere to flow through a resistance of 1 ohm.

Q. 38—Then there is no standard volt, like the standard pound used as the unit of pressure?

A.—There is a scientific standard which need not be considered in practical work. The ampere and ohm have physical standards, as given above, and these determine the practical value of the volt.

Q. 39—What other names are given to electrical pressure?

A.—Electromotive force, difference of potential, tension and voltage; electromotive force is generally written E.M.F., or E, as in Ohm's law, when it is expressed in symbols.

Q. 40—What is Ohm's law?

A.—The current, expressed in amperes, that passes through a wire or other conductor, is equal to the E.M.F. in volts, that urges it on, divided by the resistance of the conductor, in ohms, that opposes the passage.

Q. 41—How is this law expressed in symbols?

A.—

$$C = \frac{E}{R},$$

in which C = current in amperes, E = electromotive force in volts and R = resistance in ohms.

(This notation is in general use, and will be employed throughout the rest of this catechism without further explanation.)

Q. 42—Deduce the value of E from the equation given under Question 41.

A.—

$$E = CR,$$

or, the E.M.F. is equal to the product of the current and the resistance.

Q. 43—And how is the value of R deduced?

A.— $$R = \frac{E}{C}$$

or, the resistance is equal to the E.M.F. divided by the current.

Q. 44—How much E.M.F. will a battery like that described under Question 24 generate?

A.—Such a battery is impractically weak. The commercial battery cells give an E.M.F. of a little less than 1 volt.

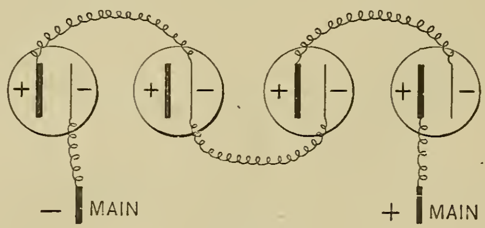


FIG. 8.

Q. 45—How can higher E.M.F. be obtained?

A.—Higher E.M.F. can be obtained by connecting a number of batteries "in series," as shown in Fig. 8. Then the E.M.F. of each cell or jar is added to that of the other cells. If each of the cells in Fig. 8 has an E.M.F. of $\frac{3}{4}$ volt, the E.M.F. at the ends marked + Main and — Main will be four times that value, or 3 volts.

Q. 46—The illustration shows the positive electrode of one jar connected to the negative of the next one all the way along. Is this intentional?

A.—Yes; the positive electrode of a cell must always be connected to the negative of its neighbor when the cells are in series, because the current must flow from positive to negative outside of

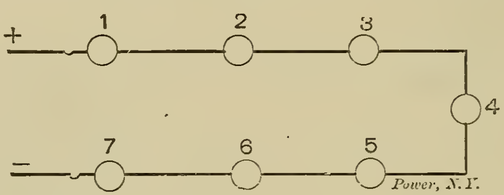


FIG. 9.

a cell, and from negative to positive inside, and if two cells of equal strength were connected, zinc to zinc, or copper to copper, they would oppose each other and no current would flow when the outer ends were connected by a wire.

Q. 47—"Connected in series" means in a row, then, one after the other?

A.—Yes. Electrical connections are effected by mere contact, and when several devices, similar or dissimilar, are arranged in contact with each other so that the whole current passes through all of them, as in Figs. 8 and 9, they are said to be connected in series.

Q. 48—What other methods of connection are used?

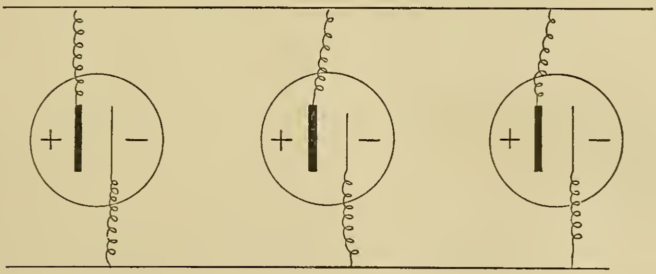


FIG. 10.

A.—Parallel, or multiple connection, as in Figs. 10 and 11, and combinations of this and the series connection.

Q. 49—What is the object in connecting up in parallel?

A.—Batteries and dynamos are connected in parallel when the E.M.F. of one is sufficient, but its current capacity is not. Adding other batteries or dynamos in parallel with one already in use does not increase the available E.M.F., but gives greater current capacity, just as connecting two or more boilers to one steam main gives more steam supply, but no greater pressure. If the output

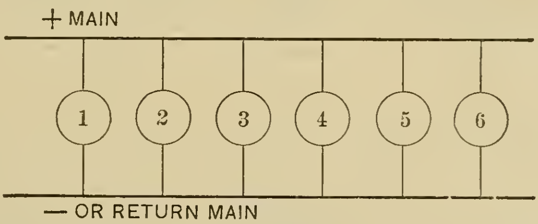


FIG. 11.

of one cell of battery were $\frac{3}{4}$ volt and $\frac{1}{6}$ ampere, the group in Fig. 8 would supply $\frac{1}{6}$ ampere at $\frac{3}{4} \times 4 =$ volts and the group in Fig. 10 would yield $\frac{1}{6} \times 3 = \frac{1}{2}$ ampere at $\frac{3}{4}$ volt.

Q. 50—What combinations of series and parallel grouping are used?

A.—Series-parallel, as shown in Fig. 12, and parallel-series, as in Fig. 13.

Q. 51—What is the difference between the result obtained by the Fig. 12 arrangement and that obtained in Fig. 13?

A.—None; in both cases the E.M.F. is $0.75 \times 3 = 0.225$ volt and the current capacity is $0.1666 \times 3 = \frac{1}{2}$ ampere, reckoning on the basis of $\frac{3}{4}$ volt and 1/6 ampere per cell.

Q. 52—Why are both methods used?

A.—Series-parallel connection is used when the current passing through the group is constant and the E.M.F. at the main terminals is variable. Parallel-series connection is used when the E.M.F. at the terminals is constant and the quantity of current

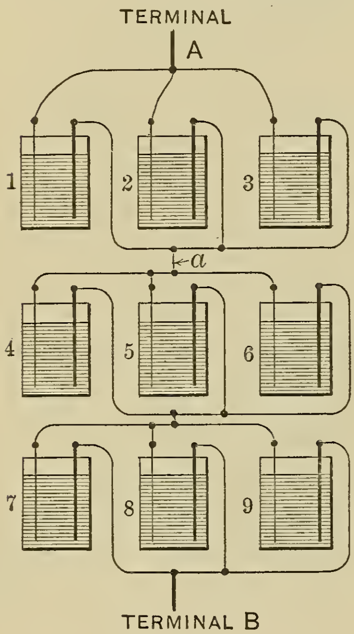


FIG. 12.

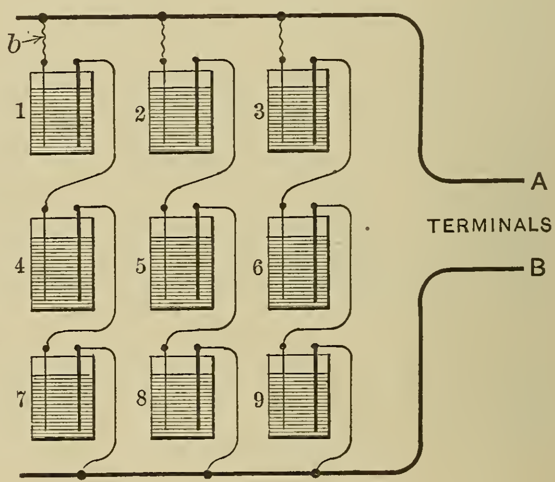


FIG. 13.

is variable. Thus, in Fig. 12, it would be troublesome to cut out the cells 1, 4 and 7 in order to reduce the current capacity, the severing of three distinct connections being necessary; on the other hand, the E.M.F. of the group may be easily reduced by transferring the main terminal, *A*, to the wire, *a*, involving a single operation and cutting out the cells, 1, 2, 3. In Fig. 13, on the contrary, the current capacity is reduced by simply disconnecting the wire, *b*, and throwing out cells 1, 4 and 7, but it would be troublesome to vary the E.M.F. by cutting out and in the cells, 1, 2 and 3.

Q. 53—Are other devices than batteries connected in series-parallel and parallel-series?

A.—Yes; incandescent lamps are sometimes so connected, and magnet coils are frequently combined in such groups. Figs. 14 and 15 show groups of devices arranged to correspond with the battery groups in Figs. 12 and 13.

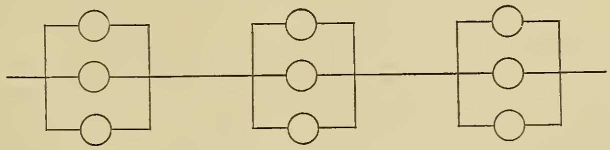


FIG. 14.

Q. 54—Is there any rule applying to the connection of electrical devices?

A.—No specific rule is needed. As a guide, for use until the underlying principles become thoroughly familiar, the following will serve:

I.—*Connecting devices in series adds their individual E.M.F's and resistances; the current capacity of a series group is limited to the capacity of the weakest member.*

II.—*Connecting devices in parallel add their individual current capacities. The E.M.F. of parallel sources of current is that of the strongest member; they should be equal. The allowable voltage of a group of receptive devices in parallel is limited to that of the weakest member; all should be equal. The total resistance*

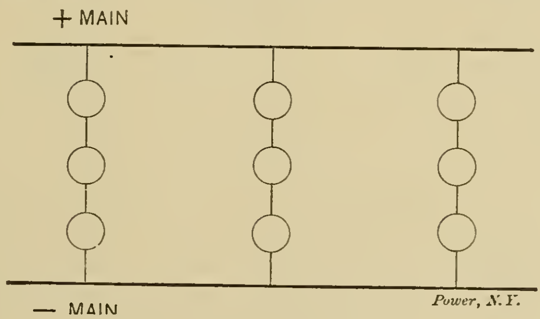


FIG. 15.

of a parallel group of devices of equal resistances is the resistance of one device divided by the number of them.

III.—*In series-parallel groups each sub-group of devices in parallel may be considered a unit member with reference to the entire group.*

IV.—*In parallel-series groups each sub-group of devices in series may be considered a unit member with reference to the entire group.*

Q. 55—In Fig. 11, why does not all the current pass through the nearest lamp, marked 1?

A.—Because its resistance is too high. The current that passes through each lamp of the group follows Ohm's law (page 7), and therefore is equal to the potential difference, *E*, between the mains, measured at the ends of the cross wires (called "taps"), divided by the resistance, *R*, of each tap and lamp from main to main. A hydraulic analogue is represented by Fig. 16, where *P* is a pump, taking water from a tank, *R*, and forcing it through six water-motors. The pipes, *A* and *B*, correspond with the mains of a parallel circuit (Fig. 11), and the little pipes connecting the motors with the mains correspond with the taps.

Q. 56—How is electrical power calculated?

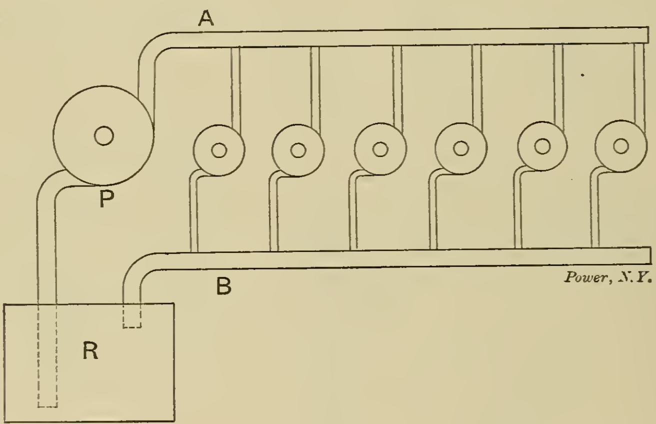


FIG. 16.

A.—In watts, the unit being named for James Watt. One watt is 1 ampere flowing under E.M.F. of 1 volt. Multiplying the amperes flowing in a circuit by the volts at the terminals gives the watts that are being applied to that circuit, or the rate of electrical working.

Q. 57—How does a watt compare with a mechanical horse-power?"

A.—One horse-power equals 746 watts.*

* This equivalent is always used in practice. The actual value is 745.956 watts.

Q. 58—Is there an electrical unit corresponding to the mechanical foot-pound?

A.—Yes, in function but not exactly in value. The joule is the electrical unit of work, and is equal to 1 watt for one second of time. One watt for one minute, therefore, equals 60 joules, and 10 watts for one minute = 600 joules.

Q. 59—What is the relation between joules and foot-pounds?

A.—One joule equals 1.35625 foot-pounds; or 1 foot-pound equals 0.7373 joule.

Q. 60—Are there other electrical units?

A.—Yes; derived units, such as watt-hour, meaning 1 watt one hour; kilowatt, meaning 1000 watts; kilojoule, meaning 1000 joules; kilowatt-hour, etc.

Q. 61—Why are so many units necessary?

A.—They are not necessary—merely convenient. It is easier to say and write 10 kilowatts, than 10,000 watts. Moreover, the physical conception is easier, as a kilowatt is nearer a horse-power in value, and we are accustomed to reckoning in horse-powers.

Q. 62—Are these units represented by symbol letters?

A.—Most of them are. Watts are usually represented by W, and kilowatt is universally written KW. Joules are generally represented by J. Using these symbols, and representing seconds of time by t, and horse-power by HP, the relations of the various principal units may be summarized for convenient reference as below:

$$W = C^2 \times R = \frac{E^2}{R} = C \times E \quad \ldots\ldots \quad (1)$$

$$W = 746 \times HP \quad \ldots\ldots \quad (2)$$

$$W = J \div t = Q \times E \div t \quad \ldots\ldots \quad (3)$$

$$W = \frac{1.3563 \times Ft.Lbs.}{t} = \frac{Ft.Lbs.}{0.7373 \times t} \quad \ldots\ldots \quad (4)$$

$$J = W \times t = C^2 \times R \times t = \frac{E^2 \times t}{R} Q \times E \quad \ldots\ldots \quad (5)$$

$$J = 746 \times t \times HP \quad \ldots\ldots \quad (6)$$

$$J = 1.3563 \times Ft.Lbs. = Ft.Lbs. \div 0.7373 \quad \ldots\ldots \quad (7)$$

$$Ft.Lbs. = 0.7373 \times J = 0.7373 \times Q \times E \quad \ldots\ldots \quad (8)$$

$$Ft.Lbs. = 550 \times t \times HP \quad \ldots\ldots \quad (9)$$

$$Ft.Lbs = 0.7373 \times t \times W = \frac{t \times W}{1.3563} \quad (10)$$

$$HP = W \div 746 = 0.00134 \times W \quad (11)$$

$$HP = \frac{Ft.Lbs.}{550 \times t} \quad (12)$$

$$HP = \frac{J}{746 \times t} = \frac{Q \times E}{746 \times t} \quad (13)$$

$$HP = KW \div 0.746 = KW \times 1.34^{*} \quad (14)$$

$$KW = 0.746 \times HP = HP \div 1.34^{*} \quad (15)$$

$$KW = \frac{1356.3 \times Ft.Lbs.}{t} \quad (16)$$

* Approximate. More accurately, 1.34056.

CHAPTER II.

MAGNETISM.

Q. 63—What is a magnet?

A.—A magnet is a bar of iron or steel which possesses the power of attracting iron, steel, and in a slight degree, nickel.

Q. 64—What is this power called, and how else is it manifested?

A.—Magnetism; its presence may be clearly shown by sprinkling iron filings on a sheet of paper under which a magnet is held. If the magnet is a straight bar the filings will arrange themselves as shown in Fig. 17. The distribution of the filings indicates that magnetism consists of invisible lines of force, and it is conse-

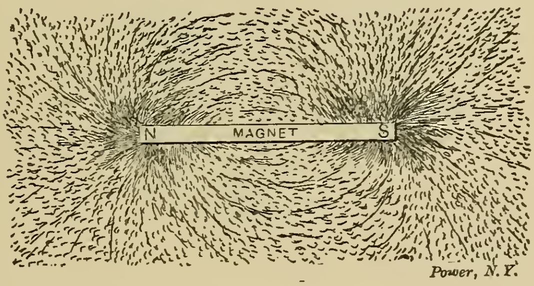


FIG. 17.

quently regarded and spoken of as "lines of force," and "magnetic lines."

Q. 65—What other term is used to describe magnetism?

A.—Magnetic flux; and where the flux passes from pole to pole of a magnet through air or other non-magnetic material it is called the magnetic field.

Q. 66—Is non-magnetic material an insulator for magnetism?

A.—No. There is no magnetic insulator. All materials except iron, steel and nickel, are poor magnetic conductors, of practically equal magnetic resistance; iron and steel are good conductors of magnetism, hence they are called magnetic material. Magnetizable material would be a more correct term, but it is cumbersome.

Q. 67—In which direction do magnetic lines flow?

A.—From the north to the south pole* of a magnet, outside of the magnet, and from the south to the north pole within the magnet, as shown in Fig. 18.

Q. 68—What are the "poles" of a magnet?

A.—The ends from, and to which, the magnetic flux passes.

Q. 69—What is an electro-magnet?

A.—If a wire be wound around a bar of soft iron or steel, as in Fig. 19, and a current sent through the wire, the bar will be found to be magnetized as long as the current is passing. If the bar is of

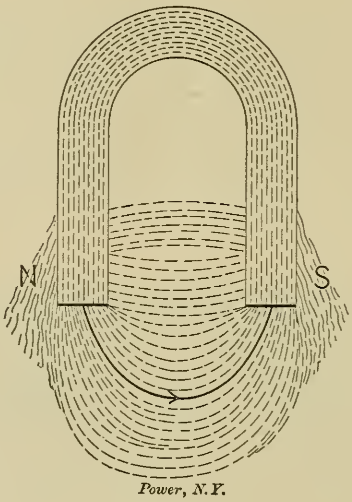


FIG. 18.

soft iron it will be very strongly magnetized, but will not retain its magnetism for any length of time after the current ceases to flow. If the bar is of steel, it will not be magnetized so strongly nor so quickly, but it will retain its magnetism for a greater length of time after the current is shut off. Such an arrangement is an electro-magnet.

Q. 70—Does it make any difference how the wire is wound around the bar?

A.—Yes; it should be wound continuously in one (either) direction. Then the polarity, or location of the poles, of the bar depends on the way the current flows through the wire.

Q. 71—How may the polarity of a magnet be determined?

A.—If the current passes around the magnet clockwise, as in

* More accurately, the north-seeking and south-seeking poles. The north pole of a compass needle is the one which points north.

Fig. 19, the magnetic flux in the magnet will be *away* from the observed end of it. For example, if current passes around the hand spindles of a clock in the direction its hands travel, the end of the spindle on which the hands are mounted will be the south

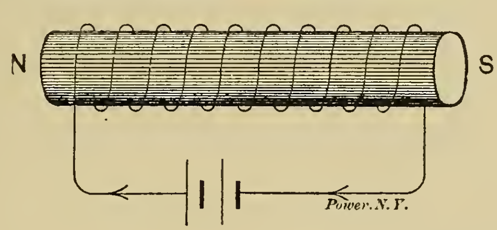


FIG. 19.

pole. The poles may be identified by holding a permanent magnet, or a compass needle, near one pole of the electro-magnet; the north pole of one will attract the south pole of the other, and *vice versa.*

Q. 72—What governs the strength of a magnet?

A.—The number of ampere-turns* in the magnetizing coil and the quality of the path through which the flux passes. Magnetic lines form closed loops, as indicated by Figs. 20 and 21, and the strength of the magnetic flux is measured in lines per square inch

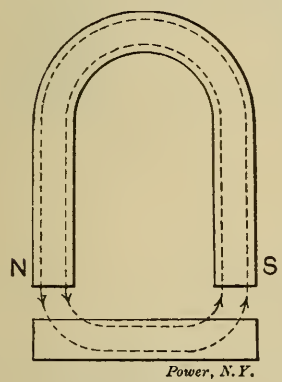


FIG. 20.

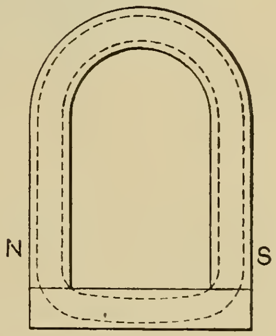


FIG. 21.

area of path. This number is greater the greater the exciting force in ampere-turns, or the better the magnetic quality of the pathway.

Q. 73—What determines the "quality of the pathway?"

A.—The material. Annealed wrought iron is the best; annealed

---

* Ampere = turns = Ampères of current passing through a coil × number of turns of wire in the coil.

cast steel comes next and soft cast iron third. Air and metals other than iron and steel are the poorest.

Q. 74—Why does a magnet draw other pieces of iron to it?

A.—Because (1) the iron is a better conductor of magnetism than air and (2) lines of force exert their powers in the direction of shortening their travel. Hence, a piece of iron placed within range of the flux from a magnet and left free to move, as in Fig. 20, will be pulled into that position which gives the lines of force

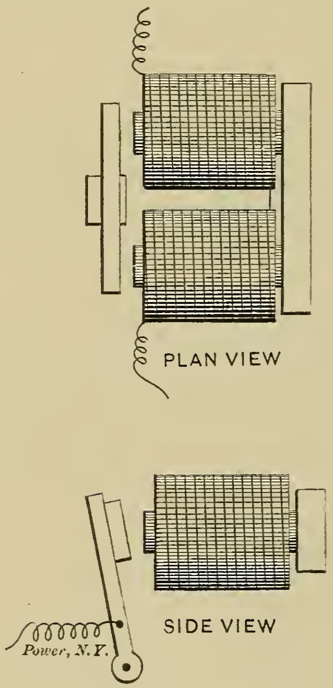


FIG. 22.

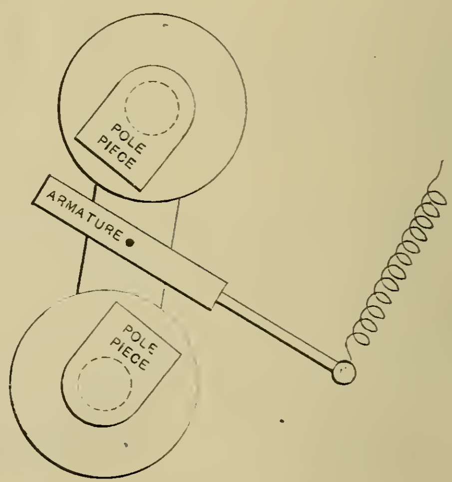


FIG. 23.

the shortest path through it from the north to the south pole of the magnet—namely, in contact with both poles, as in Fig. 21.

Q. 75—Are magnets used to operate mechanism by their power of attraction?

A.—Yes; in numerous devices, of which some of the most familiar are electric bells, electric arc lamps, automatic electric regulators, electric locks and telegraph instruments.

Q. 76—What is the name of the movable piece upon which the magnet exerts its pull?

A.—The armature. Fig. 22 shows a typical arrangement of a magnet with an armature pivoted at one end. Fig. 23 shows one with the armature pivoted in the center. In both and any cases,

the armature will always be drawn into that position which gives the magnetic lines of force the shortest path from pole to pole through the armature, within the range of its movement.

Q. 77—Is there any limit to the magnetic flux that can be forced through iron and steel?

TABLE II

DENSITY OF MAGNETIZATION.	PERMEABILITY.			
Lines Per Square Inch B"	Annealed Wrought Iron.	Commercial Wrought Iron.	Gray Cast Iron.	Ordinary Cast Iron.
20.000	2,600	1,800	850	650
25.000	2,900	2,000	800	700
30,000	3,000	2,100	600	770
35,000	2,950	2,150	400	800
40 000	2,900	2,130	250	770
45 000	2,800	2,100	140	730
50 000	2,650	2,050	110	700
55,000	2,500	1,980	90	600
60,000	2,300	1 850	70	500
65 000	2,100	1,700	50	450
70,000	1,800	1,550	35	350
75,000	1,500	1,400	25	250
80,000	1,200	1,250	20	200
85,000	1,000	1,100	15	150
90,000	800	900	12	100
95,000	530	680	10	70
100,000	360	500	9	50
105,000	260	360	...	...
110,000	180	260	...	...
115 000	120	190	...	...
120,000	80	150	...	...
125 000	50	120	...	...
130,000	30	100	...	...
135,000	20	85	...	...
140,000	15	75	...	...

A.—Yes; beyond certain degrees of magnetization, called "working points," the magnetic resistance of iron increases so rapidly that a considerable increase in magnetizing power produces only a small increase in magnetism. Then the magnet core is said to be nearing "saturation." Finally a point is reached when an increase in magnetizing power produces no appreciable increase in magnetism; then the core is saturated.* Table II. gives the permeability of various grades of iron and steel at dif-

* When a cloth is so wet that further application of water does not add to its moisture, it is "saturated." Similarly, when a piece of iron does not appreciably increase in magnetic strength under an increase in magnetizing force, it is called "saturated."

ferent degrees of magnetization. Permeability is the ability to conduct magnetism or to contain magnetic lines. It corresponds to the electrical conductivity of wires.

Q. 78—Is there a name for magnetic resistance?

A.—Yes; reluctance. The law of the magnetic circuit is analogous to Ohm's law for electrical circuits; namely,

$$\text{Flux} = \frac{\text{Magnetizing force}}{\text{Reluctance}}$$

But the calculation of a magnetic circuit is much more difficult than that of an electric circuit, because of the leakage of magnetic lines; there being no such thing as an insulator of magnetism. If we represent ampere-turns by M, the permeability of the material by μ, the area of the magnetic pathway by a, its length by l, and the total number of magnetic lines by Φ, the formula in symbol is:

$$\frac{M \times a \mu}{9.3133 \times l} = \Phi \ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

if leakage is neglected. In many cases it is more convenient to reckon in magnetic "density" instead of total flux; if the magnetic density, in lines of force per square inch of cross-section is represented by B we can use the formulas

$$B = \frac{M \times \mu}{0.3133 \times l} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

$$\text{and } M = \frac{0.3133 \times l\, B}{\mu} \ldots\ldots\ldots\ldots\ldots\ldots (19)$$

for iron and steel. Where the lines pass through air the permeability, μ, is 1, and may be omitted.

Q. 79—How is the permeability of iron and steel obtained?

A.—The permeability is equal to the value of Φ when iron is the magnetic conductor of the flux, divided by the value of Φ when air is the conductor. Thus, if we pass current through a coil of wire, as in Fig. 24, even though there is no iron core present, magnetic lines will be created, and form closed circuits, as indicated by the dotted lines. Now, suppose we measure the flux passing through the hollow of the coil and find 1000 lines. Then if we insert an iron core and connect its ends with a yoke so as to give a complete circuit of iron, as in Fig. 25, and find that the

number of lines through the coil has risen to 500,000, with the same number of ampere-turns, the "permeability" of the iron core will be $\frac{500,000}{1000} = 500$.

Q. 80—How are the lines of force in the coil and in the iron core measured?

A.—There are several methods of measuring them, all of which are of a scientific nature and need not be discussed here. The instrument usually used in measuring the lines is called a ballistic

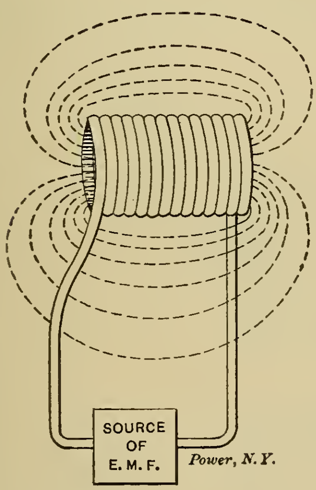


FIG. 24.

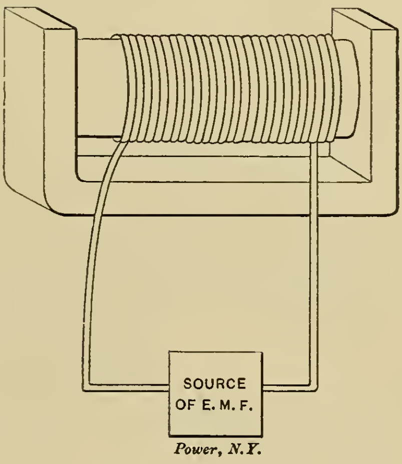


FIG. 25.

galvanometer. Its use is described in more advanced text books.

Q. 81—What is the unit of permeability?

A.—There is no unit; it is simply the ratio between the flux in iron or steel and that in air, with a given magnetizing force.

Q. 82—If magnetism is created by a coil alone, as in Fig. 24, is not the coil a magnet?

A.—Yes, literally. A distinction is made in practice, however, between a coil alone and a coil on a core. The coil alone is called a solenoid.

Q. 83—Are solenoids used in electrical apparatus?

A.—Yes; for many purposes, as in arc lamps and regulators.

Q. 84—Why is it not better to put a core in the coil, if it increases the magnetism so greatly?

A.—It is, when the magnetic attraction is exerted over very short distances. But where the armature or moving member must have a long range of action without excessive variation in the "pull" exerted upon it by the coil, a solenoid is preferable, though weaker than a magnet.

Q. 85—How is a solenoid used?

A.—In connection with an iron plunger, as shown by Fig. 26. This plunger takes the place of the armature of a magnet, and its movement is due to the same cause; namely, the effort of magnetic lines of force to shorten the length of their path and improve its quality.

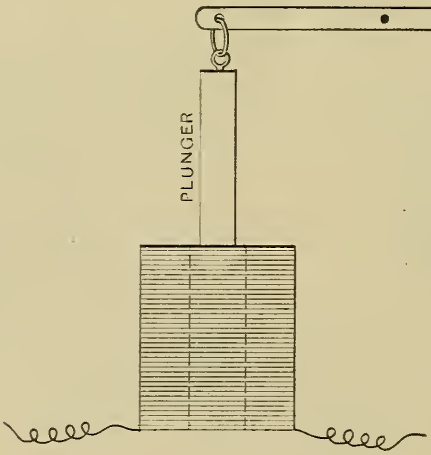


FIG. 26.

Q. 86—Why do the lines of force pull a plunger further than an armature?

A.—Because the plunger has to move a greater distance from the point where it is just within range to the point where it gives the lines their shortest path through it. Figs. 27 and 28 give the comparison. In Fig. 27 the lines have to reach out the same distance from the solenoid to the plunger that they do from the magnet core to the armature; in Fig. 28 the plunger has moved many times the distance traversed by the armature in order to reach the "shortest path" position.

Q. 87—Is not a solenoid more efficient than a magnet then, on account of its long pulling range?

A.—No; because the strength of the pull is much less than that of a magnet.

Q. 88—What limits the range of pull of a solenoid?

A.—Its own length. At the start the plunger end should be just at the end of the coil or a trifle within it; the plunger will be drawn through until its ends project equal distances beyond the ends of the coil, as in Fig. 28. The pull at the start is comparatively weak, gradually increasing as the plunger enters and falling off again as its end approaches the distant end of the coil. There is a long range, however, of strong pull within the coil.

Q. 89—In Fig. 17, 18, 20 and 21, the magnets shown have no coils of wire on them. Why is this?

A.—They are permanent magnets; Fig. 17 is a "bar" magnet and the others are "horse-shoe" magnets.

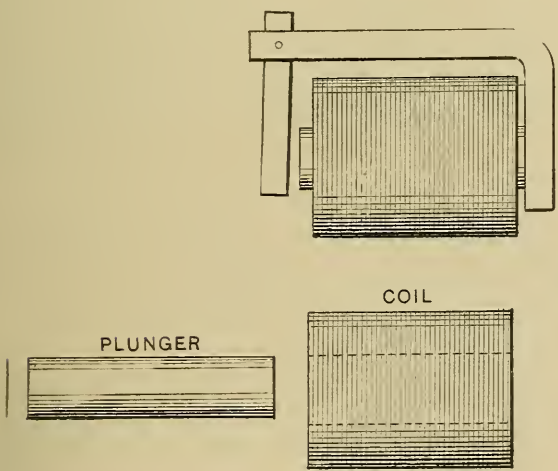


FIG. 27.

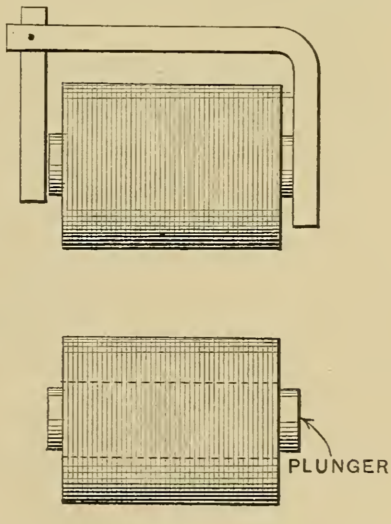


FIG. 28.

Q. 90—How does a permanent magnet differ from an electro-magnet?

A.—When once magnetized, it remains so indefinitely. Such a magnet is made of hard steel. Soft iron or steel will not retain magnetism an appreciable length of time after the magnetizing power is withdrawn, and for that reason it is preferable for electro-magnets whose strength is required to respond to variations in the magnetizing power of their coils.

Q. 91—What are permanent magnets used for?

A.—To furnish the "magnetic field" in measuring instruments, such as voltmeters and ammeters, and in the familiar magneto-

electric machines used in some telephone systems and for testing purposes.

Q. 92—How is a piece of steel made into a permanent magnet?

A.—Either by winding a coil on it and sending a powerful current through the coil, or by rubbing it on the poles of a powerful electro-magnet.

Q. 93—What is the best material for permanent magnets?

A.—Tungsten steel or chrome steel. The analyses of tungsten and chrome steels are as follows:

TUNGSTEN STEEL.		CHROME STEEL.	
Iron	95.371	Iron	97.893
Carbon	.511	Carbon	.687
Manganese	.625	Manganese	.028
Silicon	.021	Sulphur	.020
Phosphorus	.028	Silicon	.134
Tungsten*	3.444	Phosphorus	.043
		Chromium*	1.195

* Tungsten and chromium are minerals.

CHAPTER III.

PRINCIPLES OF DYNAMO AND MOTOR CONSTRUCTION.

Q. 94—Under Question 35 it was stated that a dynamo generates E.M.F. by induction; what is induction?

A.—The induction there mentioned is magneto-electric* induction, or the inducing of electricity by magnetism. The creation of magnetic lines of force by means of a current of electricity is electro-magnetic* induction. (See Q. 69.)

Q. 95—How is magneto-electric induction obtained?

A.—Either by moving a conductor (such as a wire) through a stationary magnetic field at right angles to the flux, as in Fig.

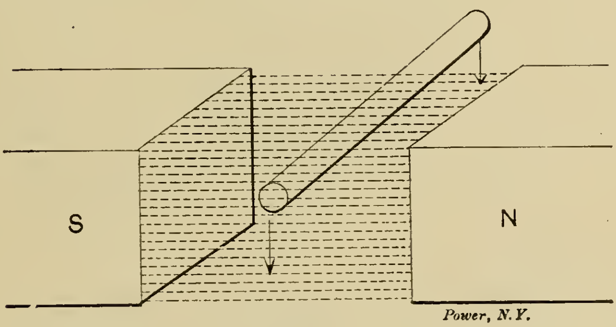


FIG. 29.

29, or by moving the magnetic field so as to cause the lines to be cut by a stationary conductor.

Q. 96—How much E.M.F. is generated by moving a wire across lines of force?

A.—One volt for each 100,000,000 lines passed per second by the wire. This moving across lines of force is called "cutting." If 100,000,000 lines of force are passing from *N* to *S*, Fig. 29, and the wire were carried downward at such a rate of speed that it moved from one edge of the magnetic field to the other in one second, it would "cut" 100,000,000 lines per second, and 1 volt E.M.F. would be generated in it.

* Magneto-electric, meaning, roughly, magnetism converted into electricity. Electro-magnetic, meaning, roughly, electricity converted into magnetism.

Q. 97—Then it would only be necessary to move the wire back and forth across the magnetic field in order to keep generating E.M.F.?

A.—Yes; but when it is moved *upward* the E.M.F. is reversed in direction, so that if it were simply moved back and forth, and its ends were connected by a wire outside of the field, the current in the closed circuit would flow first in one direction and then in the other; this sort of current is called "alternating."

Q. 98—How is the wire moved across the magnetic field in a dynamo?

A.—Many wires are used instead of one, and these are laid along a cylindrical iron structure, called the armature core, which is revolved so as to carry the wires across the field many times per second, but in a curved path instead of a straight line. Reference to Fig. 30 will make this clear. The lines of force pass from

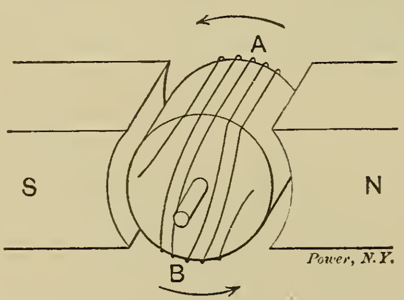


FIG. 30.

N to the iron cylinder and from that to *S*; revolving the cylinder will cause the wires wound on the cylinder to cut across the lines of force, and an E.M.F. will be generated in the wires. If the ends of the coil are connected together or to an outside conductor, current will flow.

Q. 99—But half of the wires move upward, while the other half move downward. Does not this interfere?

A.—No; although the half, *A*, is cutting lines in one direction when the half, *B*, is cutting in the opposite direction, the flow through all parts of the coil agrees. Thus, when *A* passes downward between *S* and the core, the current tends to flow from the front end of the core to the back in *A*; as *B* is passing upward between *N* and the core, the current in *B* tends to flow from back to front of the core, joining its effort, through the wires across the ends, with that in *A*.

Q. 100—But when *A* comes around to *N* and moves upward, is not the E.M.F. reversed, as it was in the single wire?

A.—Yes. In order to prevent the reversal of the E.M.F. from reversing the direction of current flow outside of the dynamo, a

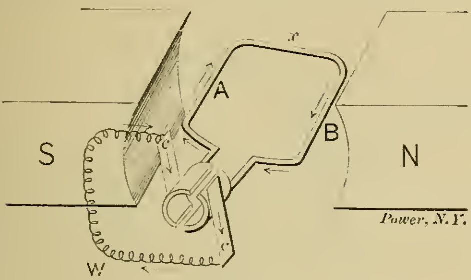


FIG. 31.

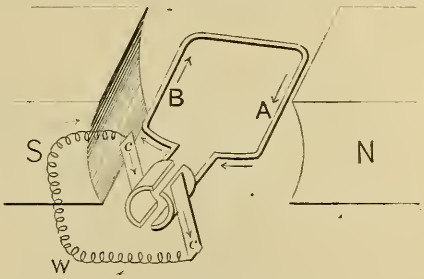


FIG. 32.

"commutator" is used, as shown in elementary form in Figs. 31 and 32. Here the armature coil is shown with only one turn, the armature core is omitted and the magnet poles are drawn further apart, for the sake of clearness. The direction of the current flow is indicated by arrows. In Fig. 31 the *A* part of the coil is going downward past the *S* pole, and in Fig. 32 it is coming upward past the *N* pole. Although the current flow has reversed in the coil itself, the flow is not changed in the outside circuit, *W*, because the commutator has changed the connections. The strips, *c* and *c*, are called brushes.

Q. 101—Has a dynamo armature only one coil?

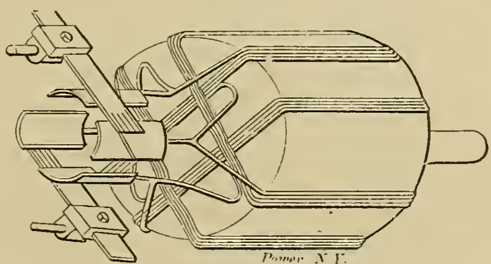


FIG. 33.

A.—No; it has a great many. Fig. 33 shows a four-coil armature, and the number of coils may be made almost anything. In practice the number ranges from sixteen to several hundred, according to the size and type of the dynamo.

Q. 102—Why is the revolving part of a dynamo given the same name as the strip of iron in Figs. 20 and 21?

A.—Because it bears the same general relation to the dynamo magnet, known as the field magnet, that the iron bar does to the small magnet; namely, it furnishes a good path for the magnetic flux passing from pole to pole of the magnet.

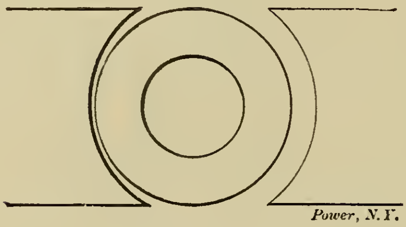


FIG. 34.

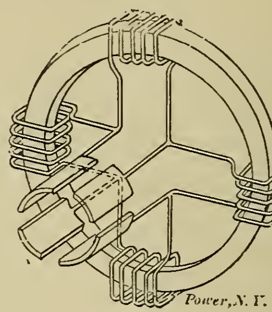


FIG. 35.

Q. 103—Why is not the armature drawn against the magnet poles?

A.—Because the pull of one pole is balanced by that of the other, the distance between armature and magnet being the same on both sides. If the armature is not accurately centered between the poles, as in Fig. 34, there is a heavy pull toward the nearest magnet pole, which greatly increases the friction of the bearings and is liable to spring the armature shaft.

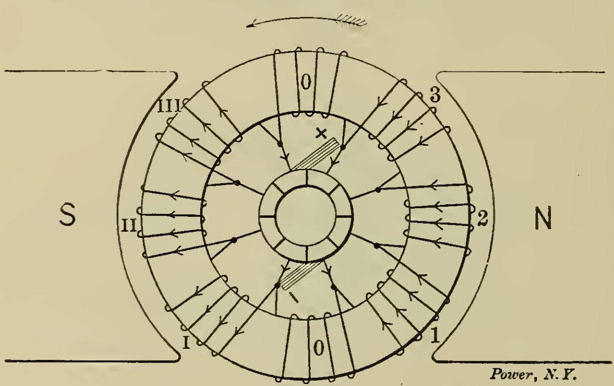


FIG. 36.

Q. 104—Are all dynamo armatures alike?

A.—No; there are two general classes, the *drum* armature, of which Figs. 31, 32 and 33 are elementary forms, and the *ring* armature, shown in elementary form by Figs. 35 and 36. The ring winding is simpler than the drum winding, but not quite so effi-

cient because of the greater resistance of the wire for a given size of armature. In the ring armature the lines of force separate and travel through opposite halves of the ring-shaped core, as

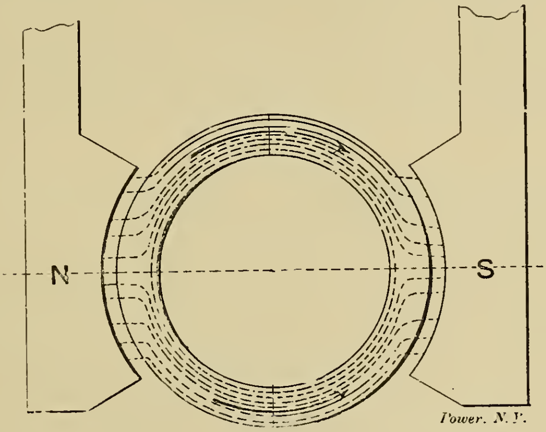


FIG. 37.

indicated in Fig. 37, while the lines go nearly straight through a drum core, as shown by Fig. 38.

Q. 105—Why are so many wires put on a dynamo armature?

A.—To obtain the required E.M.F. at a reasonable speed and with a reasonable size of machine. The E.M.F. of one wire is added to that of any other wire connected in series with it so that the direction of flow agrees. In Fig. 31, for example, if the wire,

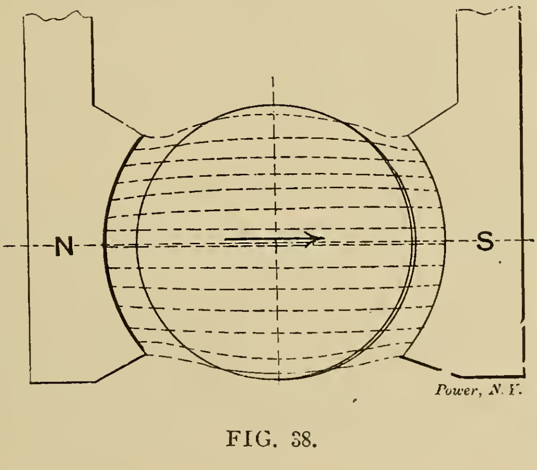


FIG. 38.

A, was cutting lines of force and generating an average E.M.F. of 1 volt in the direction of the arrow, and the wire, *B*, were doing the same thing, joining the ends by the piece of wire, *x*, out-

side of the magnetic field, would cause the two E.M.F's to add (See Q. 54) and 2 volts would be the E.M.F. at the free ends connected to the commutator. Most of the wires on an armature core are so arranged that their E.M.F's are added in a similar manner. If they were not, the magnet would need to be of enormous size or the armature would have to run at an enormous speed.

Q. 106—How do the size of the magnet and the speed of the armature affect the E.M.F. of the machine?

A.—The E.M.F. furnished by each armature conductor is proportional to the number of magnetic lines cut per second by that conductor and the number of conductors in series multiplied by the E.M.F. of one gives the E.M.F. of the machine. The size of the magnet determines the number of magnetic lines in the field, and the speed of the armature determines the number of times these lines are cut per second by each conductor. If the number of lines passing from pole to pole through the armature be represented by Φ ; the number of wires all around the outside surface of the armature by w; the number of paths through the armature winding by b, and the revolutions per minute by S, the E.M.F. at the brushes will be found by the formula—

$$E = \frac{2 \times \Phi \times w \times Rev.}{6.900.000.000 \times b} \text{ or } \frac{\Phi \times w \times Rev.}{3.000.000.000 \times b} \quad \ldots\ldots\ldots\ldots (20)$$

Q. 107—What determines the amount of current that a dynamo can give?

A.—The size of the wire used on the armature and the manner of connecting the winding.

Q. 108—What effect has the size of the wire?

A.—The larger the wire the more current it will carry without overheating.

Q. 109—How does the size of the wire affect its heating?

A.—Forcing current through it develops heat, just as forcing anything through a pipe would; the electrical resistance of the wire being similar to the mechanical resistance of the wall of the pipe.

Q. 110—How much heat is developed in a wire per ampere of current?

A.—The heat units developed per second are proportional to the

watts passed through the wire. The rise in temperature is proportional to the watts divided by the affective radiating surface.

Q. 111—How can the heat units be calculated?

A.—As 778 heat units equal 1 foot-pound, and 1.35625 foot-pounds per second equal 1 watt (see page 13), 1055.1625 heat units per second will be developed when 1 watt is applied to a circuit.

Q. 112—How can the rise in temperature be computed?

A.—It cannot be accurately computed for an armature except by comparison with an actual case, because the rapid motion of the armature surface increases its radiating capacity. For field

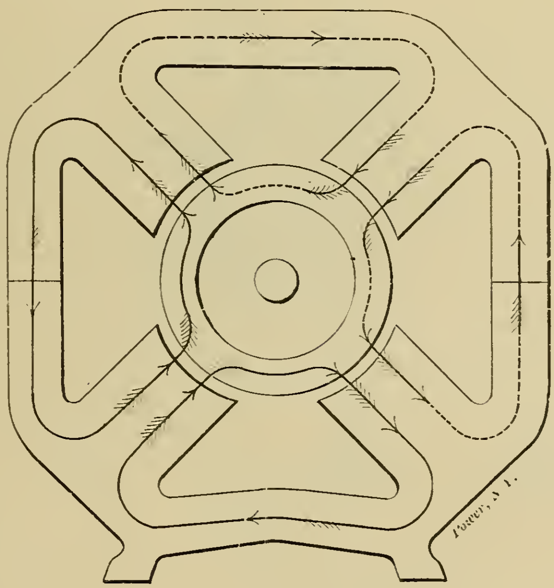


FIG. 39.

magnet and other motionless coils the rise in temperature is practically equal to 200 times the number of watts divided by the radiating surface in square inches. In formula shape,

$$\frac{200 \times W}{S} = \text{Rise in Fahrenheit degrees.}$$

Q. 113—How does the manner of connecting the armature winding affect its capacity for current?

A.—If there are two paths through the armature winding, the total allowable current will be twice the capacity of the armature

wire; if there are four paths, the armature winding will stand four times the current that the armature wire can carry without overheating. This is simply because the paths through the armature winding are in parallel. (See answer II. to Q. 54, page 11.)

Q. 114—What is meant by the number of paths through the armature winding?

A.—Reference to Fig. 36 will make this clear. Tracing the current from the — brush through to the + brush, it will be seen that it divides, half going through coils 1, 2 and 3, and half through coils I., II. and III. There are, consequently, two routes or paths through the winding.

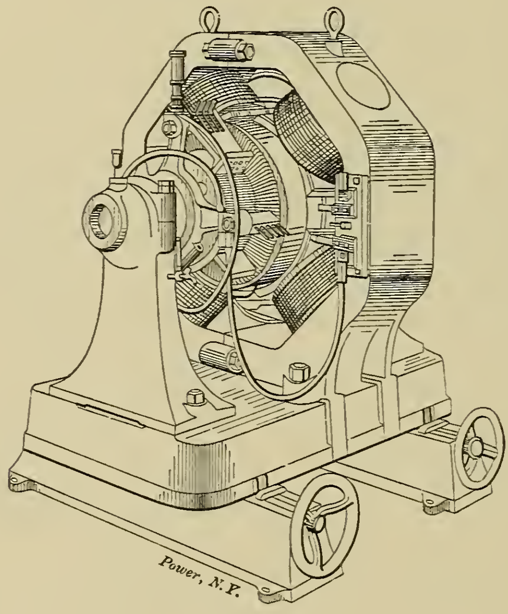


FIG. 40.

Q. 115—Are there ever more than two paths?

A.—Frequently. In multipolar dynamos there are usually as many paths through the armature as there are poles on the machine.

Q. 116—What is a multipolar dynamo?

A.—One having more than two poles. Fig. 39 shows one plan of field magnet having four poles. The dotted lines and arrows indicate the courses taken by the magnetic lines. The north poles may be identified by the arrows passing from the magnet to the armature, the south poles being those to which the lines return.

Fig. 40 gives a perspective view of a machine having this type of magnet.

Q. 117—How is the armature winding of such a machine arranged?

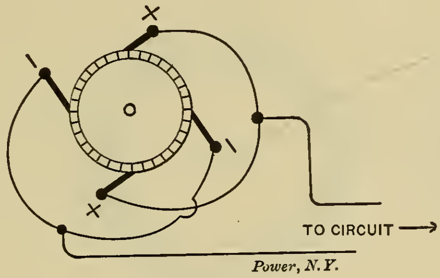


FIG. 41.

A.—A ring winding is arranged exactly the same as in a bipolar machine, but two extra brushes are applied to the commutator, as shown in Fig. 41, two being positive and two being negative. The two positive brushes are connected together and form one positive armature terminal; the two negative brushes are similarly connected and form the negative terminal. A drum winding may be arranged exactly as it is for a bipolar field, and the two additional brushes used. In practice, however, the coils are wound so that when one side is under one magnet pole the other side is under

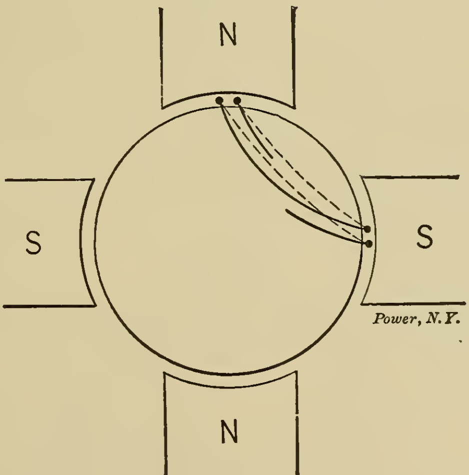


FIG. 42.

the neighboring magnet pole, instead of being diametrically opposite. This arrangement makes the ends of the coils shorter and reduces their resistance. Fig. 42 shows a coil consisting of two turns of wire, wound for a four-pole field. The dotted lines indi-

cate the wires across the far end of the core. The connections to the commutator are usually the same as in the bipolar machine, and brushes are added as in Fig. 41.

Q. 118—Is the armature core a solid piece of iron?

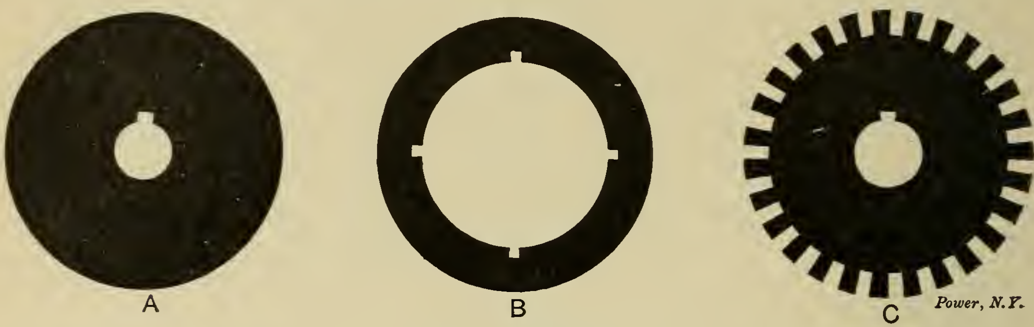


FIG. 43.

A.—No; it is always "laminated," which means divided up into thin sheets or plates. These plates are insulated from each other by a thin coat of varnish or by sheets of tissue paper of the same shape as the iron plates, in order to prevent the generation of eddy currents in the core. In Fig. 43, *A* is a plain drum core disk; *B* is a plain ring core disk and *C* is a slotted drum core disk, which is the kind mostly used in this country.

Q. 119—What are the slots for in *C*?

A.—To contain the armature wires. Instead of laying them along the surface of the core they are put in the slots.

Q. 120—What is the advantage of such construction?

A.—The air gap, or distance between the iron of the armature and that of the pole pieces, is considerably reduced, and as air is

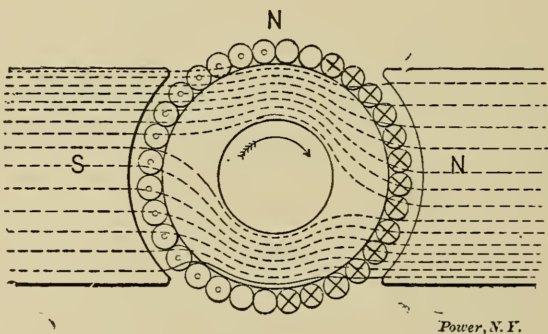


FIG. 44.

a poor magnetic conductor, shortening this air gap greatly reduces the magnetic resistance or reluctance of the path of the magnetic

flux. Furthermore, the armature wires are better protected against mechanical injury and displacement than when on the surface of the core.

Q. 121—What are eddy currents?

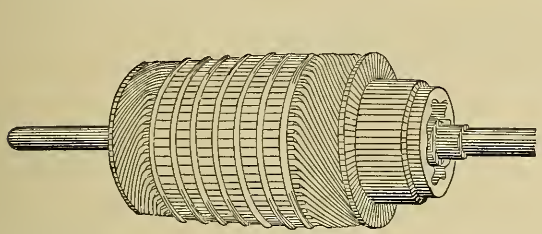


FIG. 45.

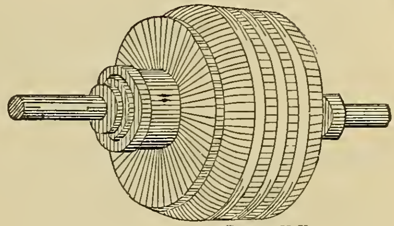
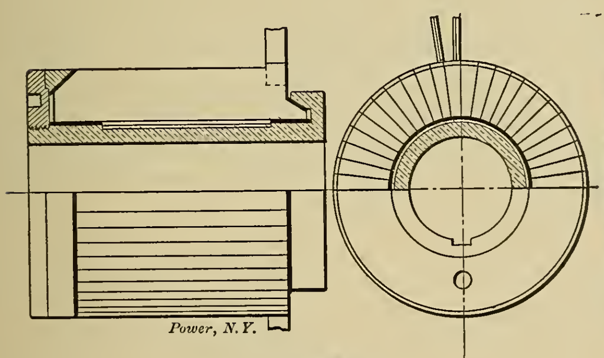


FIG. 45A.

A.—Currents generated in masses of metal which cut lines of force, and are allowed to circulate at random. Fig. 44 shows how the induced current flows in the wires of an armature; the current is coming toward the observer in the $\odot$ wires and going the other way in the $\otimes$ wires. If the armature core were a solid piece, cur-



FIGS. 46-47.

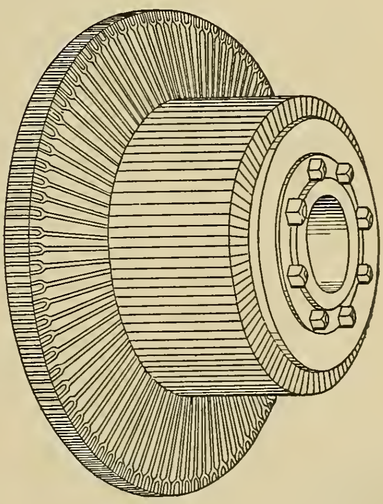


FIG. 48.

rent would flow from end to end in it just as in the wires. It is in order to prevent this that the core is made up of plates or disks electrically separated by either enamel or tissue paper.

Q. 122—What is the appearance of a complete armature?

A.—Fig. 45 shows a drum armature and commutator, complete with the shaft, and Fig. 45-A shows a ring armature complete.

Q. 123—In Figs. 36, 41 and 45, the parts of the commutator are not separated as in Figs. 31 to 35. Why is this?

A.—Because a continuous smooth surface is necessary for the brushes to rest upon. The copper bars of the commutator are

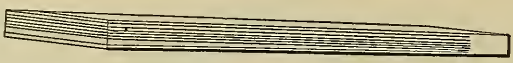


FIG. 49.

electrically separated by mica strips, as shown in the end view of the commutator in Fig. 47. Fig. 46 shows the side view, the upper half sectional. The heavy black lines represent insulating material, such as mica. Fig. 48 shows a complete commutator.

Q. 124—Are all brushes flat strips, as in Fig. 32?

A.—No; few are. Copper brushes are made up of strips of thin

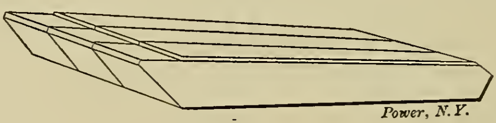


FIG. 50.

sheet copper, soldered together at one end, as in Fig. 49. The free ends are cut to a bevel, as in Fig. 50, to give a large contact surface next to the commutator. The position of such a brush relative to the commutator is shown by Fig. 51. Brushes are also made of carbon blocks, sometimes to the shape shown by Fig. 50, which type is set at an angle like a copper brush; sometimes the

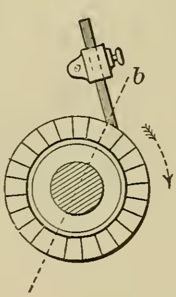


FIG. 51.

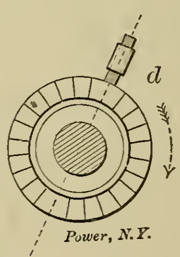


FIG. 52.

carbon brush is a simple rectangular block and set radially on the commutator, as in Fig. 52.

Q. 125—Why is carbon used for a brush?

A.—Because it reduces "sparking" or "flashing" as the com-

mutator bars pass the brush. Fig. 53 shows what occurs when a bar passes from beneath a brush. In the position shown, the armature coil, *C*, is "short-circuited" by the brush and no current flows through it, the currents from the coils on each side of it going directly to the brush from the commutator segments, *c* and *d*. When the bar, *c*, passes beyond the brush the current flow between them is interrupted and the current compelled to go through the coil, *C*, of higher resistance. This causes a spark from *c* to the brush. The higher the resistance of the coil, the worse will be the spark. Conversely, the higher the resistance of the bridge formed by the end of the brush from *c* to *d*, the smaller will be the spark. Carbon has a much greater resistance than copper, hence its use here greatly reduces the sparking.

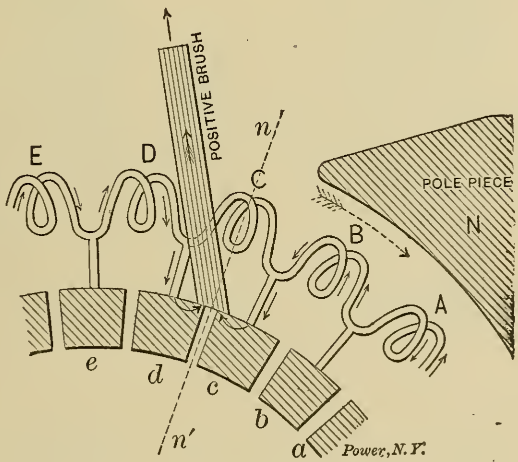


FIG. 53.

Q. 126—Under Q. 117 it was stated that the ends of copper brushes were beveled to give a large contact surface. Why is a large surface desired?

A.—To reduce the resistance of the contact and, consequently, the heating and loss of energy.*

Q. 127—Does not the use of a carbon brush cause heating on account of its high resistance?

A.—It would if the brushes were made of as small area as copper brushes. In practice they are much thicker and wider than copper brushes would be under like conditions.

*Commonly called the C^2R loss, because $C^2 \times R =$ watts, and watts $\times$ seconds $=$ work or expended energy.

Q. 128—Is there any guide for the area of the brush contact?

A.—Yes; a series of experiments has demonstrated that the area of a copper brush contact should not be less than 4 square inches per 1000 amperes, and that of a carbon brush should not be less than $2\frac{2}{3}$ square inches per 100 amperes. Expressing it differently, the current should not exceed 250 amperes per square inch for copper, and $37\frac{1}{2}$ amperes for carbon brush contacts. As the thickness of a brush should not be greater than two to three times the thickness of one commutator segment, the desired contact area is obtained by using several brushes side by side, as shown in Fig. 54.

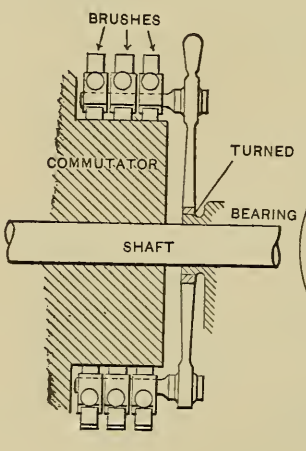


FIG. 54.

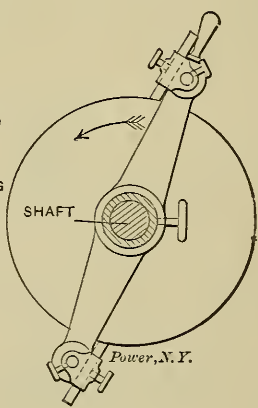


FIG. 54A.

Q. 129—What determines the points of the commutator upon which the brushes should touch?

A.—The field magnet. Each brush must touch at such points that the coil, which is short-circuited by it, as in Fig. 53, is cutting the smallest possible number of lines of force. In a bipolar dynamo the wires represented by plain circles in Fig. 44 are in this position, and the bars to which they are connected will be those upon which the brushes must rest at the instant referred to by the drawing. The points of contact are sometimes called "neutral" points, meaning that the coils which the brushes short-circuit at those points are neutral, or not generating any E.M.F. The brushes are always mounted on a rocker-arm or a ring, which enables one to shift them around the commutator and find the non-sparking position. (See Fig. 54-A.)

Q. 130—Where does the field magnet get the current to excite its coils?

A.—From its own armature. The whole current sent out by a "series-wound" dynamo passes through its field magnet coils, as shown by Fig. 55. Hence the name "series wound"—the magnet coils are in series with the work circuit and armature. In a "shunt-wound" dynamo, only a small part of the total current passes through the magnet coils, as they are of high resistance

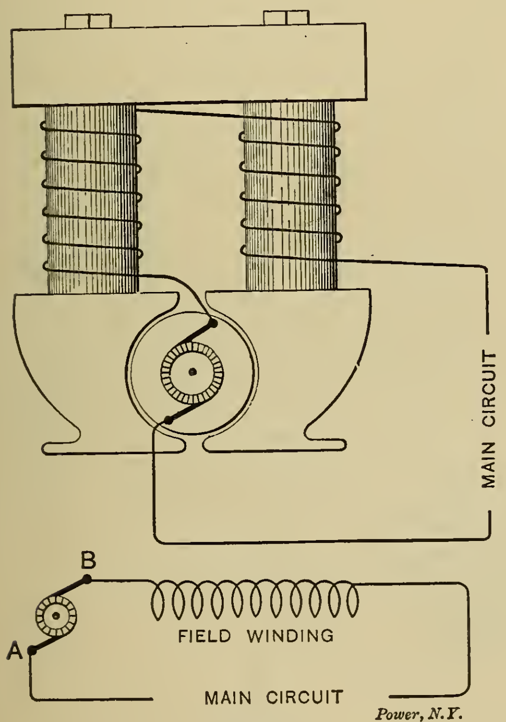


FIG. 55.

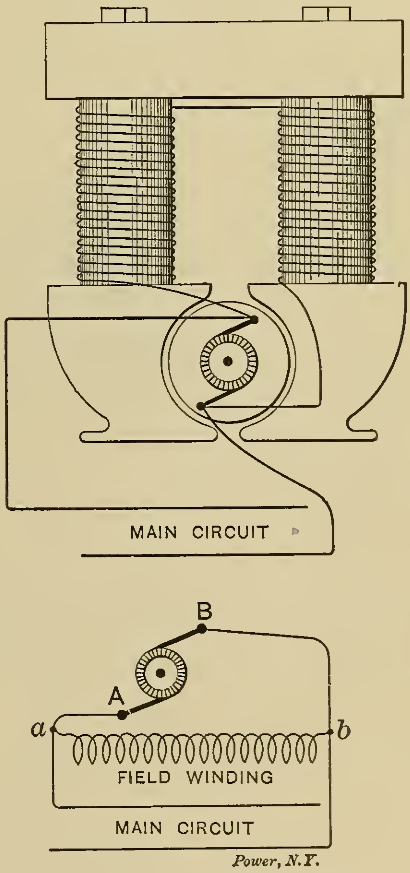


FIG. 56.

and connected so as to form a "shunt" to the outside circuit, as in Fig. 56. The lower diagrams show more clearly the electrical relations of the dynamo windings to the outside circuits.

Q. 131—What is meant by a shunt?

A.—A by-path in parallel with the principal circuit is a "shunt." In Fig. 56 the outside circuit is the principal one, and the field winding is therefore a "shunt" as compared with it.

Q. 132—When a dynamo is at rest and no current is flowing, how is the field magnet magnetized?

A.—All iron masses retain a small amount of magnetism after having once been magnetized. This "residual" magnetism in-

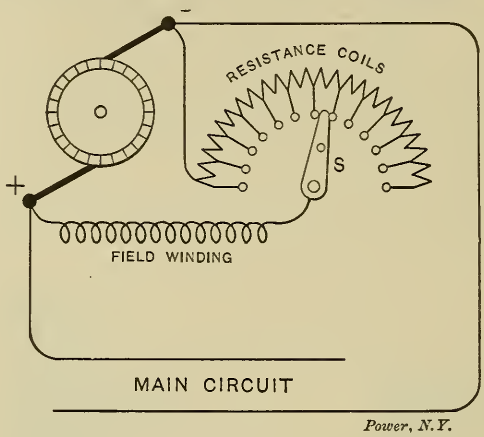


FIG. 57.

duces a very feeble E.M.F. in the armature, and a little current passes through the field-magnet coils, increasing the magnetism. This, in turn, increases the flow of current, and the "excitation" of the field continues to increase to the normal point. When a

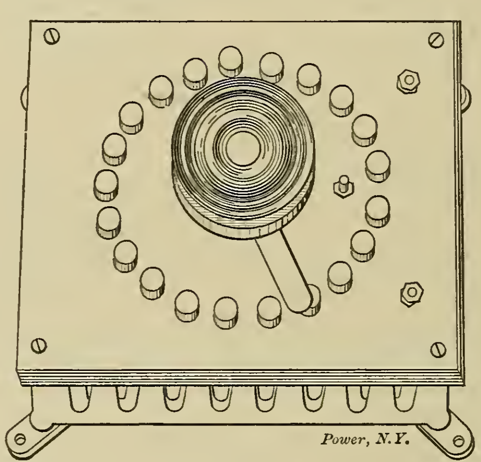


FIG. 58.

dynamo is first tested after building, the exciting current is obtained from some other source.

Q. 133—How is the E.M.F. of a dynamo regulated?

A.—By varying the strength of the field magnet. In a shunt-wound dynamo this is accomplished by putting resistance coils in

series with the field winding, and cutting in or out the resistance coils by means of a metal contact finger (*s*, in Fig. 57) traveling over metal contact buttons to which the resistance coils are connected. The complete apparatus is called a rheostat; Fig. 58

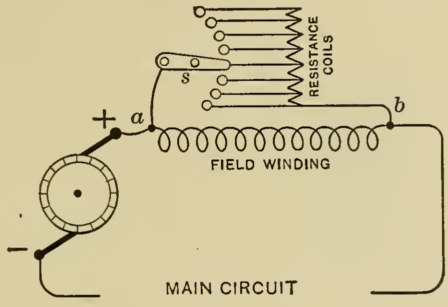


FIG. 59.

shows a modern rheostat. Series-wound dynamos are regulated sometimes by a rheostat connected in shunt to the field-magnet coils, as in Fig. 59. The current passing from *a* to *b* divides between the magnet coils and the rheostat coils; the higher the resistance of the rheostat the less current passes through it, and the more through the magnet coils, hence the stronger the field magnet. Another method consists of cutting in or out of circuit sections of the field magnet winding, as in Fig. 60. The object of all these methods is to vary the strength of the field magnet, and, thus, the E.M.F. of the armature. (See page 30.)

Q. 134—What is the reason for using different field windings?

A.—To suit the machine to different requirements. A series-

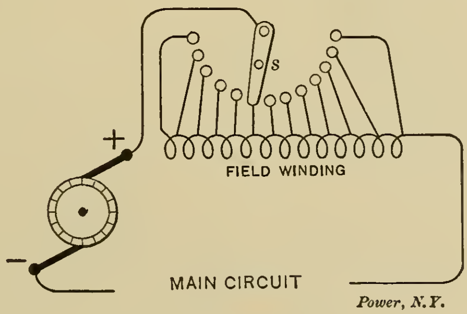
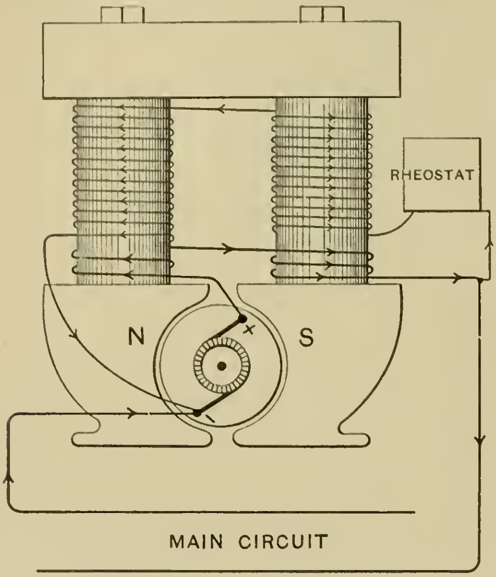


FIG. 60.

wound dynamo is used when the current in the main circuit is to remain unchanged, because the E.M.F. at the brushes is always very high—usually several thousand volts—and if the field coils were connected in shunt their resistance would have to be very

high, necessitating the use of very fine wire, so that the cost of wire would be much greater than with series coils of heavy wire. As the current does not fluctuate very much, the whole of it can be passed through the field coils. Such an arrangement is known



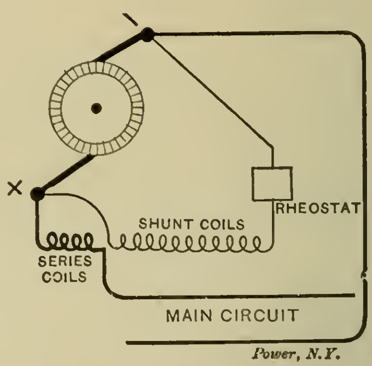


FIG. 62.

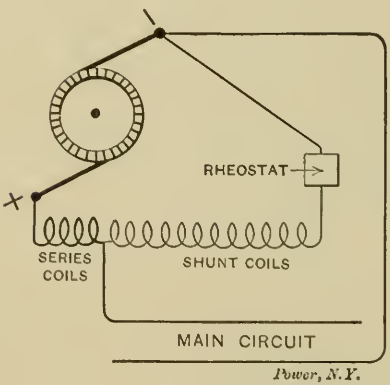


FIG. 61.

as a constant-current system. It is used in arc lighting, where all the lamps are connected in series, as in Fig. 9.

Q. 135—How is a shunt-wound dynamo used?

A.—For supplying a "constant-potential" system, such as incandescent lamp circuits (see Fig. 11), and power circuits. Here the E.M.F. or potential* remains practically unchanged and the

* A contraction of the term "difference of potential."

current varies according to the load. Hence, a series-wound dynamo could not be used satisfactorily because its field strength would fluctuate with the load, and when the latter fell to a small value, the dynamo field would be too weak to keep up the E.M.F.

Q. 136—Are there any other forms of field magnet winding?

A.—Yes; compound windings are extensively used for constant potential dynamos. Fig. 61 shows the usual arrangement. The field magnet windings are divided into two parts, fine wire coils in shunt to the circuit, marked "shunt coils" in the lower diagram, and heavy wire coils in series, marked "series coils." The shunt coils supply most of the field strength, and their effect is regulated

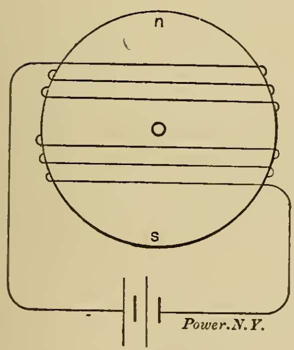


FIG. 63.

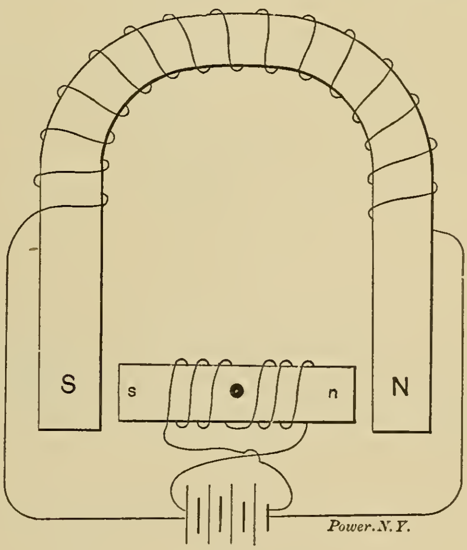


FIG. 63A.

by a rheostat, exactly as in the plain shunt-wound dynamo. In some cases the shunt coils are connected in shunt to the brushes, as shown in Fig. 62; such an arrangement is known as a "short shunt" connection, and that of Fig. 61 is called a "long shunt," because it shunts both the armature circuit and the series coils.

Q. 137—What effect do the series coils give?

A.—They serve to increase the total field strength as the load increases. Thus, when there is no load the shunt coils excite the field alone. As the load comes on, the main current flowing through the series coils adds to the field strength; and any increase in load will increase the field strength some, but not in direct proportion, of course.

Q. 138—What is the object of increasing the field strength with the load?

A.—To increase the E.M.F. generated in the armature, and thus compensate for the loss in the armature circuit. (See Q. 200.)

Q. 139—What is the difference between a dynamo and a motor?

A.—Practically, there is none. The construction is substantially the same, and a dynamo may be used as a motor or *vice versa.*

Q. 140—How is it that the same machine can be used either to generate current or to be driven by the current?

A.—Because any machine that will convert motion into another form of energy, will, if supplied with that form of energy, con-

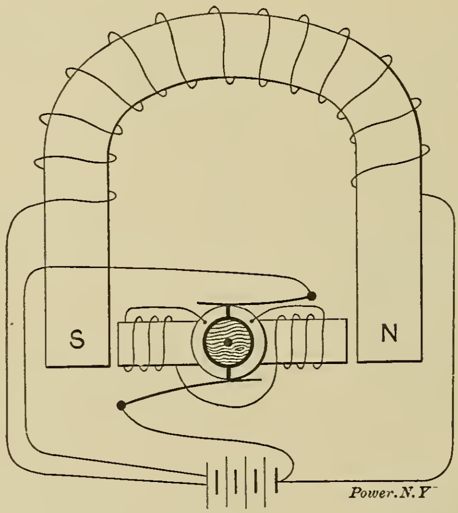


FIG. 64.

vert it back into motion. Consider the case of an air compressor, power pump, steam engine or any other machine for changing energy from some other form to motion or *vice versa.* A hydraulic pump, if supplied with water under pressure, will be driven by it as a motor; so also will an air compressor.

Q. 141—How does the current cause a motor armature to turn?

A.—Part of the current is used to magnetize the field magnet; the remainder goes through the armature and, in effect, magnetizes it, and the two magnetic fields that are set up attract each other and cause the armature to turn. Reference to Figs. 63 to 67 and the answer to Q. 76 will explain. Fig. 63 shows a single coil wound on an iron core which is free to revolve around its

center. Passing a current through the coil creates magnetic "poles" at *n* and *s*. Now mount this core between two magnet poles, as in Fig. 63-A, and it will turn until its *n* pole is opposite the *S* pole of the magnet.

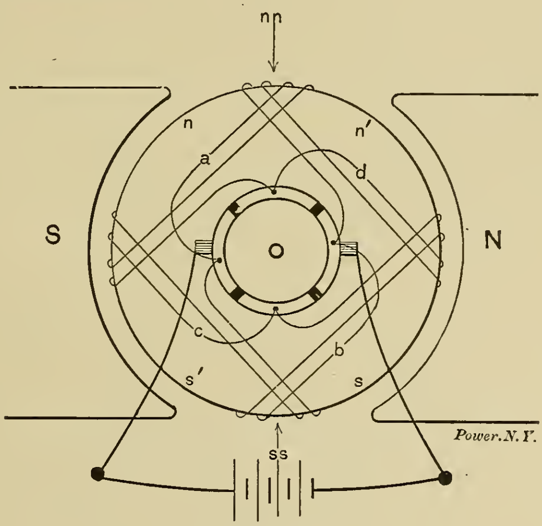


FIG. 65.

Q. 142—Will it not come to a rest in that position?

A.—It would, but for the commutator. Fig. 64 shows the one-coil armature with a commutator. The brushes are so set that the

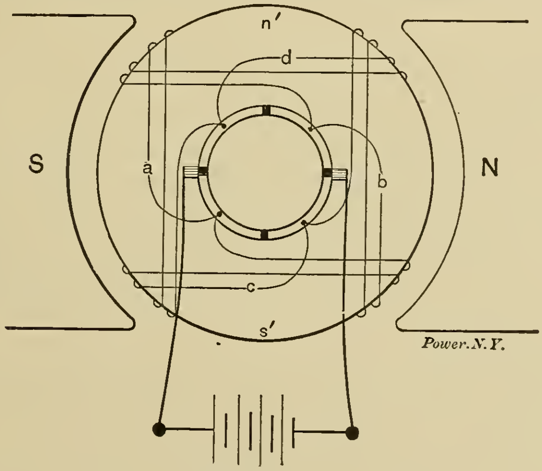


FIG. 66.

current is reversed in the coil just as *n* and *S* are opposite, so that *n* becomes *s* and repels the *S* pole of the magnet.

Q. 143—How is it when several coils are used on the armature core?

A.—The combined effects of all the coils result in setting up a magnetic field corresponding with that of a single coil. Fig. 65 shows four coils, *a, b, c* and *d; a* and *b* set up a field at *n,* and an opposite one at *s; c* and *d* set up similar fields at n^1, and s^1, and these two sets combine in two fields, each spread around nearly one-half of the core, with centers at *nn* and *ss*—just where the single coil in Fig. 63 set up its fields. Fig. 66 shows the armature turned to where the coils, *a* and *b,* are "cut out" by the brushes, and Fig. 67 shows it turned a little further, with the resultant field centers, *nn* and *ss,* shifted backward.

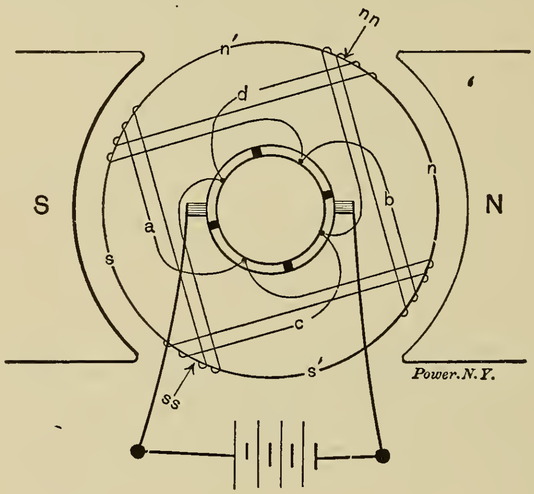


FIG. 67.

Q. 144—Then without a commutator a motor could not run?

A.—No; just as an engine could not run without a valve to reverse the application of steam to the piston when a dead center is reached. The commutator performs this function for each coil of the armature as soon as its magnetic axis coincides with that of the field magnet poles.

Q. 145—What prevents a motor from running away when the load is taken off?

A.—The armature wires generate an E.M.F. when they cut the magnetic lines of the field, just as in a dynamo. This E.M.F. is opposite in direction to the line E.M.F. which drives current through the armature so that it keeps the current down, and this keeps the speed down. This refers to a shunt-wound motor operated on a constant-potential circuit.

Q. 146—Does not the speed of a constant-potential motor ever change?

A.—Yes, a little. If the armature windings had no resistance the speed would be constant.

Q. 147—How does the resistance affect the speed?

A.—Part of the line E.M.F. is used up in forcing current through the armature resistance; this part, frequently called the *resistance-volts,* is equal to $C \times R = v$. The remainder $(E - v)$ must be exactly balanced by the back E.M.F. (e) of the motor. Now, the motor E.M.F., e, varies with the speed; hence when v increases, e must decrease, because $e + v$ must equal the line E.M.F. For example, if $C = 10$ amperes and $R = \frac{1}{2}$ ohm, v will be $\frac{1}{2} \times 10 = 5$ volts. If E is 100 volts, the motor E.M.F., e, must be $100 - 5 = 95$ volts. Now, if the load doubles, it is evident that 10 amperes will not pull it; the armature will slack up until the back E.M.F., e, drops to 90 volts, so that the resistance-volts, v, will be 10 volts and C will be 20 amperes, or twice its former value. The speed will now be $\frac{90}{95}$ or $\frac{18}{19}$ of its first value.

Q. 148—Is the motor E.M.F., e, always equal to the line E.M.F. minus the volts used up by resistance?

A.—Invariably.

Q. 149—What determines the speed at which a motor will run?

A.—The strength of the field, the number of armature wires and the resistance of the armature circuit from brush to brush.

Q. 150—How can the speed be calculated?

A.—First find v by multiplying the resistance by the current that the armature will stand. Subtracting this from the line voltage leaves the value of the back E.M.F., e. This is the product of speed, wires and magnetic field, as in a dynamo (see Q. 106), so that multiplying the wires by the field and dividing 6,000,000,-000 times e by the result gives the speed. A formula is easier to grasp. Let E represent the line voltage; e the back E.M.F. of the armature; R its resistance; C its current, b the number of paths through the winding; w the number of wires around the outside; Φ the number of magnetic lines of force passing from the field through the armature, and *Rev.* the revolutions per minute. Then the back E.M.F. will be

$$\frac{\Phi \times w \times Rev.}{3{,}000{,}000{,}000 \times b} = e \quad \text{(20a)}$$

Now, e is also equal to $E - C \times R$, so that

$$E - C \times R = \frac{\Phi \times w \times Rev.}{3{,}000{,}000{,}000 \times b}$$

Therefore,

$$Rev. = \frac{3{,}000{,}000{,}000 \times b \times (E - C \times R)}{\Phi \times w} \quad \text{(21)}$$

Q. 151—What determines the amount of load a motor can pull?

A.—The number of armature wires, current and magnetic flux determine the pull in pounds at the surface of the armature, and the speed fixes the foot-pounds per second. The pull at the surface multiplied by the radius of the armature is called torque, and is expressed in pound-feet.

Q. 152—What is the difference between foot-pounds and pound-feet?

A.—Foot-pounds are the product of weight or pull $\times$ distance of travel. Pound-feet are the product of weight or pull $\times$ leverage in feet. For example, if the total pull at the surface of a motor armature of 6 inches radius were 1000 pounds, the torque would be 500 pound-feet. If the motor speed were 600 revolutions a minute, or 10 a second, the "distance of travel" of any point on the surface would be $\frac{6.2832 \times 6 \text{ ins.} \times 10}{12} = 31.416$ feet a second, and multiplying this by the pull of 1000 pounds gives 31.416 foot-pounds per second. From which it will be seen that pound-feet and foot-pounds are proportional to each other, but the ratio varies with the speed. The relation may be analyzed as follows:

The circumference of an armature, in feet, $\times$ revolutions per second $=$ distance of travel per second. This multiplied by the pounds of pull (P) gives foot-pounds per second. The circumference $= 3.1416 \times$ diam., or $6.2832 \times$ radius. So, if *rev.* is the number of revolutions per second and r the radius in feet (or fractions of a foot),

$$6.2832 \times r \times rev. \times P = Ft.Lbs.\ per\ sec.$$

Now the torque is equal to $P \times r$, as just stated, hence if τ repre-

sents pound-feet it can be substituted for P and r, and we get

$$6.2832 \times rev. \times \tau = Ft.Lbs\ per\ sec.$$

It is customary to represent $(6.2832 \times rev.)$ by the symbol ω; using this, the formula becomes

$$\omega \times \tau = Ft.Lbs.\ per\ sec.$$

Q. 153—What is the formula for the horse-power of the motor?

A.—This may be expressed in several ways. Foot-pounds per second are changed to horse-power by dividing by 550, hence

$$\frac{6.2832 \times rev. \times \tau}{550}, \text{ or } \frac{rev. \times \tau}{87.535}, \text{ or } \frac{\omega \times \tau}{550} = H.P.$$

Q. 154—How can the torque be ascertained?

A.—If the magnetic flux (Φ) is known, the torque can be computed from the formula

$$\frac{\Phi \times w \times C}{426,096,000} = \tau \ldots\ldots\ldots\ldots\ldots (23)$$

Stated as a rule:

Multiply together the magnetic flux through the armature, the number of wires around the outside (or in slots) and the total armature current; divide the product by 426,096,000.

Q. 155—Suppose the magnetic flux is not known?

A.—The resistance of the armature is easily ascertained, either from the builders or by measurement. Having this, the horse-power may be computed without reference to the torque. Multiplying the resistance by the current gives the wasted volts; subtracting these from the line E.M.F. leaves the back E.M.F. of the motor. Multiply this by the armature current and the product will be the output in watts; divide this by 746 and you have the horse-power. The formulas are

$E - CR = e$, and

$$\frac{e \times C}{746} = HP \ldots\ldots\ldots\ldots\ldots (24)$$

Q. 156—Can the speed of a motor be regulated?

A.—Yes; in two ways. The E.M.F. applied to the brushes, which is ordinarily considered as the line E.M.F., can be cut down by putting resistance in series with the armature, as in Fig. 68. This pulls the speed down, just as the armature resistance does (see answer to Q. 147). The speed can be regulated also by varying the strength of the field magnet, which results in varying the back E.M.F., e.

Q. 157—How does the last method affect the speed?

A.—Strengthening the field reduces the speed, and weakening it increases the speed. Reference to formula (21) will show mathematically the truth of this. Φ represents the magnetic flux, and if this is increased without any other change, the value of *Rev.* will be diminished. Simple reasoning, without any mathematics, also shows it to be true. We know that the back E.M.F. can not exceed the difference between the lost volts ($C \times R$) and

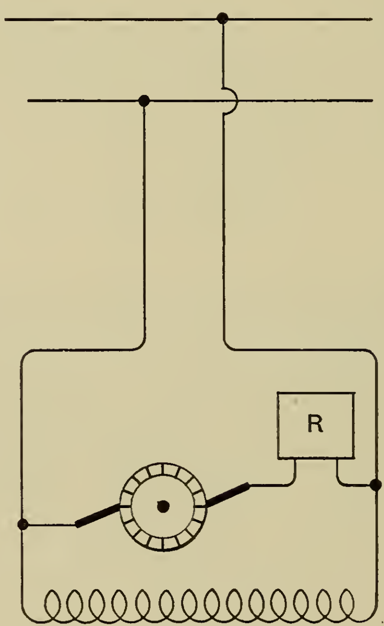


FIG. 68.

the line E.M.F.; hence, with a constant line potential and a constant load the back E.M.F. must remain constant. We further know that the back E.M.F. (the number of wires being constant) varies with the magnetism and the speed, so that in order to preserve a constant back E.M.F. the speed must be reduced if the magnetism is increased, and *vice versa.*

Q. 158—Then, as the speed increases when the magnetism decreases and *vice versa,* would not a motor run faster with no field magnetism and be brought almost to rest by making the field strong enough?

A.—No. The speed can not increase beyond the point at which the pull between the armature wires and the field magnetism is

strong enough to enable the armature to pull its load at the increased speed. And in the other direction, the magnetism can not be increased beyond the "carrying ability" of the iron cores (see Q. 77).

Q. 159—Which way is the speed of a motor usually regulated?

A.—By means of a rheostat in series with the armature. Field regulation is employed in some special cases, but the other is the common method.

Q. 160—How is a motor connected to the circuit?

A.—As shown diagrammatically by Fig. 69. The "starting box" is a rheostat, the resistance coils of which are in series with the armature at starting. They are cut out by means of the hand lever as the motor gains speed, until all are cut out of the armature circuit.

Q. 161—What are the devices indicated by *M* and *S?*

A.—Magnets. The one at *S* is usually a solenoid; it operates to open the circuit if the current exceeds a certain strength. The one at *M* holds the hand lever in the proper position for running until the current ceases; then it releases the lever, which is pulled back to the starting point by a spring.

Q. 162—How are the connections arranged inside the box?

A.—As shown by Fig. 69, which also shows the mechanical arrangement of the levers and magnets. When the current becomes too great, the solenoid, *S*, trips the latch, *l*, and this releases the lever, *A*, which is pulled by the coil spring away from its contact button (indicated by the dotted circle) and opens the circuit.

Q. 163—How does the magnet, *M*, operate?

A.—It is connected in series with the motor field winding, and, therefore, any interruption of the current flow as a whole or of that portion in the field circuit, will "kill" the magnet and allow the lever, *L*, to be thrown to the starting position, where the whole motor circuit is opened.

Q. 164—Why is the magnet connected in the field circuit?

A.—Because there it protects the motor not only in the event of a general cessation of the line current, but in case of accidental interruption of the current through the field circuit. If the magnet were in the armature circuit a break in the field circuit could not affect it.

Q. 165—Why should the motor require to be cut out in the event of a failure of the line current?

A.—In order that it may not be damaged when current is restored to the line with the armature at a standstill.

Q. 166—What would be the result if the field circuit were

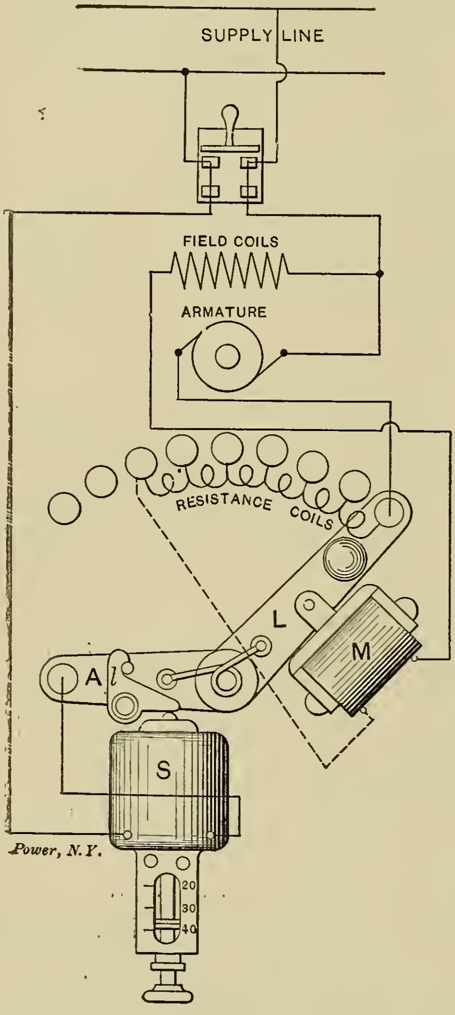


FIG. 69.

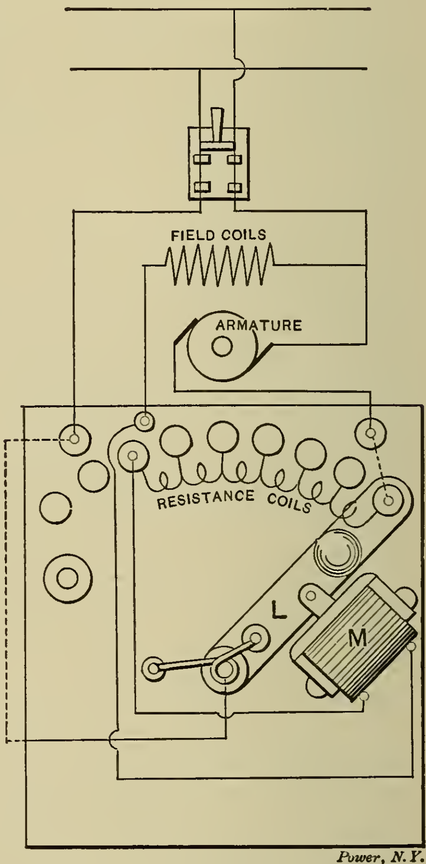


FIG. 70.

opened with the motor running, if the release magnet and spring were not there?

A.—The magnetism would cease and consequently the armature would come to rest. The current through it would rise at once to an enormous overload and cause damage, provided the overload solenoid, *S*, were also absent. With the solenoid there it would open the motor circuit.

Q. 167—Are all starting boxes made like Fig. 69?

A.—No. Many of them have only the "no-current" release magnet, as shown in Fig. 70. Fig. 71 shows an exterior view of such a box. It is, of course, preferable to have both the no-current release and the overload release.

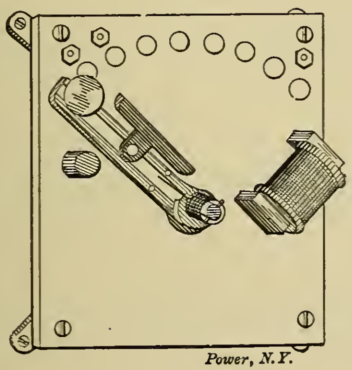


FIG. 71.

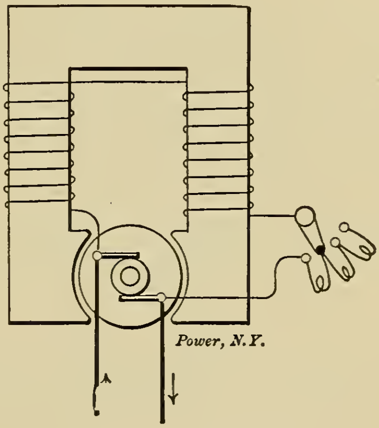


FIG. 72.

Q. 168—How are motors arranged when field regulation is used?

A.—In a variety of ways. Fig. 72 shows, in diagram, a

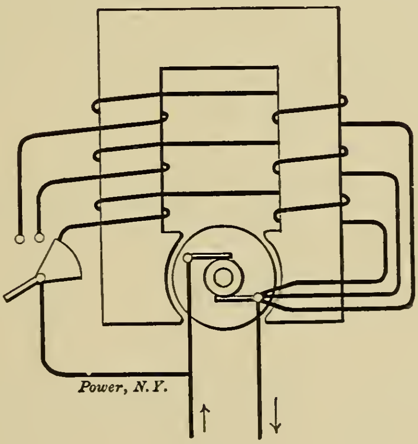


FIG. 73.

method used occasionally. A rheostat is placed in the field circuit and adjusted to vary the field strength just as in the case of a dynamo. Another method of field regulation consists of dividing the field coils into several distinct windings and connecting or disconnecting the various windings, as indicated by

Fig. 73. An elaboration of this plan consists of grouping the field windings variously by means of a special type of switch known as a controller. At the start all the windings are in series with each other, as in Fig. 74. The next movement of the switch

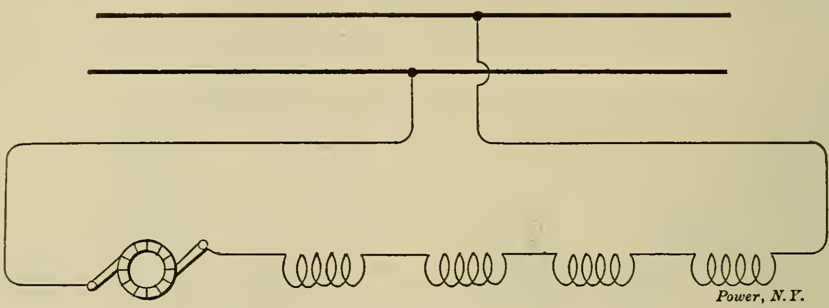


FIG. 74.

puts the windings partly in series and partly in parallel, as in Fig. 75, and so on, until the final movement puts them all in parallel with each other and in series with the armature as in Fig. 76. Each successive step reduces the resistance of the group and allows the armature to take a higher speed.

Q. 169—Is there not a change in the field magnetism when the field windings are grouped differently?

A.—Yes; the field is weakened with each change, in the progression from all-in-series to all-in-parallel, if the requisite torque remains the same or is diminished. For example, suppose for

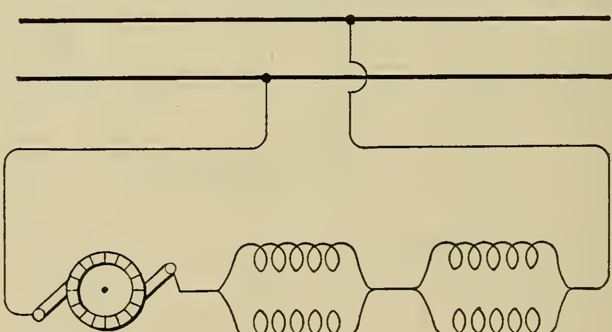


FIG. 75.

simplicity that a motor has a load requiring constant torque or "pull," at all speeds. Also assume that with full current the field magnet core is not quite saturated under the all-in-series condition of Fig. 74. Now put all of the coils in parallel, as in Fig. 76.

To give the same field strength as before, the current per coil must be the same, which would make the total current four times as great. But with four times the current in the armature the torque will be four times as great, as

$$\frac{\Phi \times W \times C}{426{,}096{,}000} = \tau.$$

In order to preserve the same torque (the torque was assumed constant), the field must weaken as much as the armature current increases; *i. e.,* the current will increase to *twice* its original value and this will give the field winding $\frac{1}{2}$ its original ampere turns. Hence, Φ will be about $\frac{1}{2}$ its first value while C is doubled. The steps between the two extremes of Figs. 74 and 76 are merely progressions in the direction of the final result.

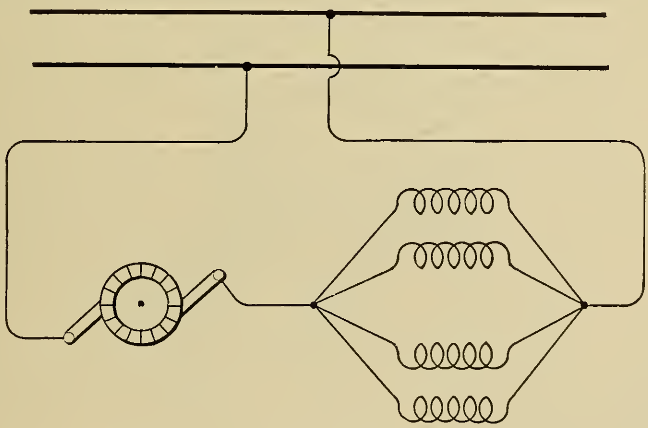


FIG. 76.

Q. 170—How is the speed affected?

A.—It is increased by reason of the two effects: the weakening of the field magnetism and the reduction of the resistance in series with the armature. When the field coils are grouped as in Fig. 76, their joint resistance is one-sixteenth of the resistance when grouped as in Fig. 74. Hence, the armature must run faster in order to generate sufficient counter E.M.F (e) to make up the difference between the volts lost in the motor windings and the line E.M.F. And as the field is weakened, the speed must be still greater in order that the back E.M.F. may equal $E - v$.

Q. 171—In the case illustrated, what would be the increase in speed?

A.—Assuming that at maximum current load (Fig. 76) the

volts lost in the armature are 2 per cent and those lost in the field are 5 per cent of the line E.M.F.; then, if the torque required by the load be constant, the speed will be a trifle over three times as great for Fig. 76 as for Fig. 74.

Q. 172—Are motors ever given compound field windings like dynamos?

A.—Yes. When a motor has both series and shunt windings, however, they are usually connected so that the series winding tends to demagnetize the field, as in Fig. 77. This is done in order to maintain a very even speed.

Q. 173—How does such a winding maintain a constant speed?

A.—As the load increases the current in the series coil increases and weakens the field just enough to make up for the loss of speed

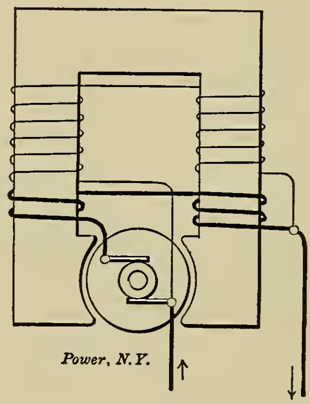


FIG. 77.

which would be caused by the increased volts lost in the armature by reason of the heavier current flowing. For ordinary purposes a plain shunt-wound motor runs at sufficiently even speed, the variation usually being well within 5 per cent.

Q. 174—What is the winding in Fig. 77 called?

A.—Differential field winding.

Q. 175—How is that of Figs. 74 to 76 distinguished?

A.—It is known as a "commutated" field.

Q. 176—In what class of work is commutated field regulation used?

A.—It is employed to control the speed of motors used in work which requires them to run continuously at any one of several speeds, or to start under heavy load, as in elevator and street railway service.

Q. 177—Does not an elevator motor require to be reversed?

A.—Yes; when the motor drives the elevator winding-drum or sheaves direct or through rigid gears, as all efficient electric elevator rigs are arranged.

Q. 178—How can a motor be reversed?

A.—By simply changing the connections between the brushes and the terminals and leaving the field connections unchanged. For example, if the motor in Fig. 78 runs in the direction indicated by the arrow when the connections are as shown, it can be made to

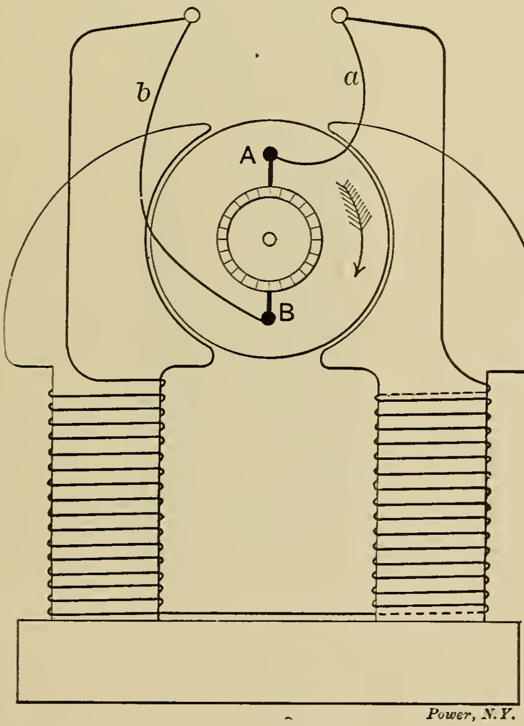


FIG. 78.

run in the other direction by connecting the wire, *a*, to the brush, *B*, and the wire, *b*, to the brush, *A*.

Q. 179—How does the controller of a commutated field motor change the field connections?

A.—Each terminal of each coil, each brush connection and each outer terminal of the entire motor is led to a spring contact finger. These fingers are arranged in a straight line parallel with the axis of a drum carrying contact strips. Rotating the drum brings these strips in contact with the fingers, and at successive positions

of the drum the connections between the fingers are changed to give the successive combination of circuits. Fig. 79 shows such a controller. The relation of each contact finger to the drum and its strip is shown by the sketch at the bottom of the cut.

Q. 180—Are there any other methods of regulating the speed of a motor?

A.—There is one other method, which is in extensive use for

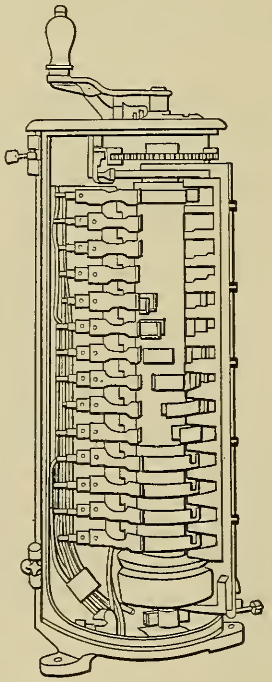
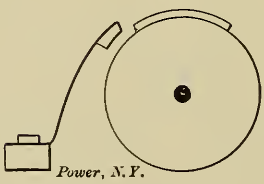
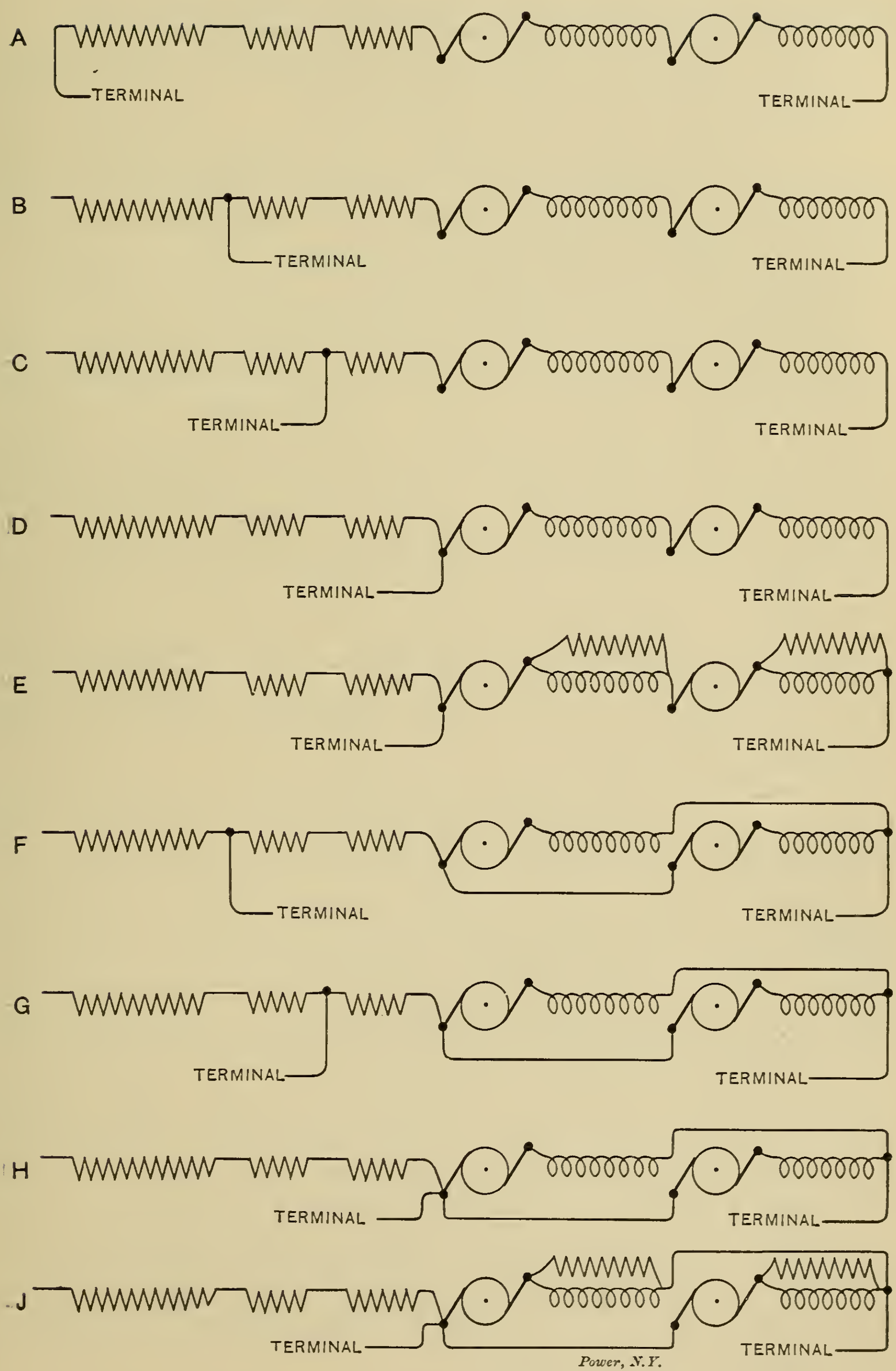


Fig. 79



speed regulation of electric railway motors. This method consists of grouping two motors first in series and then in parallel, and varying a small amount of dead resistance in series with them. A controller similar to Fig. 79 is used. Fig. 80 shows diagrammatically the successive arrangements of the circuits, from the starting point to full speed. The combinations are in-


A
TERMINAL
TERMINAL
B
TERMINAL
TERMINAL
C
TERMINAL
TERMINAL
D
TERMINAL
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E
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F
TERMINAL
TERMINAL
G
TERMINAL
TERMINAL
H
TERMINAL
TERMINAL
J
TERMINAL
TERMINAL
Power, N.Y.

FIG. 80.

dicated by the letters, *A, B, C,* etc. The zig-zag lines represent resistance coils and the spirals represent field coils.

Q. 181—Why are resistance coils connected in parallel with the field coils in the *E* and *J* combinations?

A.—To shunt part of the current out of the field magnet coils and weaken the field, increasing the speed of the motors. The *E* combination gives the greatest speed obtainable with the motors in series and the *J* combination the maximum speed in parallel.

Q. 182—What is the difference between the two speeds?

A.—That given by *J* is about twice that given by *E,* because at *J* the resistance-volts and back E.M.F. of each motor must equal the line E.M.F., while at *E* the resistance-volts and counter E.M.F. of each motor equals only one-half of the line E.M.F. At *J,* however, the resistance volts per motor are slightly greater than at *E,* hence the speed is not quite doubled.

Q. 183—Why are the resistance-volts per motor greater at *J* than at *E?*

A.—Because the motors are doing more work (driving the car at the higher speed) and the output ($C \times e$) is greater, calling for more current. And as $C \times R =$ resistance-volts (v), v will be greater than before.

Q. 184—The diagram shows series field coils; if resistance is to be used, why are shunt field coils not used?

A.—Because the motors must start under heavy loads, requiring great torque, and series field coils best fulfil this condition. Moreover, it is advisable to have the torque increase as much as possible with the load, and the maximum increase is given by series coils, because when the armature current increases the field magnetism also increases, and torque is directly proportional to Magnetic Flux $\times$ Current, as shown by formula (23). In an ordinary shunt-wound motor the field magnetism remains constant, only the armature current varying with the load.

Q. 185—Could not a railway motor be wound with series coils for starting and shunt coils for running at full speed?

A.—Yes; motors have been so built, but the slight advantage gained does not seem to justify the extra expense and complication involved in such design.

Q. 186—How is the power of a railway motor transmitted to the car axle?

A.—Through spur gears enclosed in a casing which serves the double purpose of containing a lubricant for the gears and muffling their noise.

Q. 187—How are railway motors connected in circuit when there are many cars?

A.—The individual motors of each pair are connected in series and parallel with each other, as previously described, but each complete pair constitutes a unit, and the units (car equipments) are in parallel between the circuit wires, which are nominally at constant potential.

CHAPTER IV.

CIRCUITS AND WIRING.

Q. 188—How is connection made between the car and the circuit?

A.—One terminal of the motor equipment is connected to a trolley wheel carried at the end of a pole on top of the car. This wheel rolls along a "trolley" wire suspended over the center of the track, and connected with one terminal of the dynamo. The other terminal of the dynamo is connected to the track and the car wheels form the connection between this and the other ter-

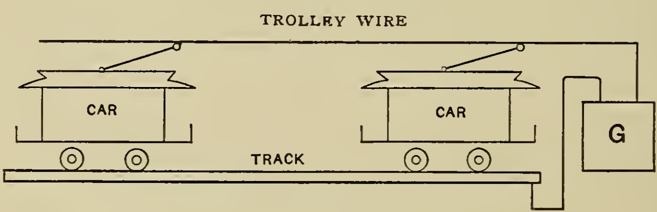

FIG. 81.

minal of the motor equipment. See Fig. 81, where the generator is represented by *G*. Fig. 82 shows roughly the car circuits; a controller stands on each platform and wires connect both controllers with the motors, *M, M,* in accordance with the requirements of Fig. 80.

Q. 189—What are the circles marked *L?*

A.—Incandescent lamps for illuminating the car.

Q. 190—Why are they connected in series?

A.—Because the circuit E.M.F. is too high to connect them in parallel. The E.M.F. commonly employed is 500 to 600 volts, and no incandescent lamps are made to stand that potential.

Q. 191—Are several dynamos worked together on a single circuit, like motors?

A.—Frequently; especially on constant-potential circuits. Fig. 83 shows diagrammatically two shunt-wound dynamos connected

to one circuit; *A* and *B* are the commutators (the armatures are omitted for simplicity) and the horizontal lines marked + bus-

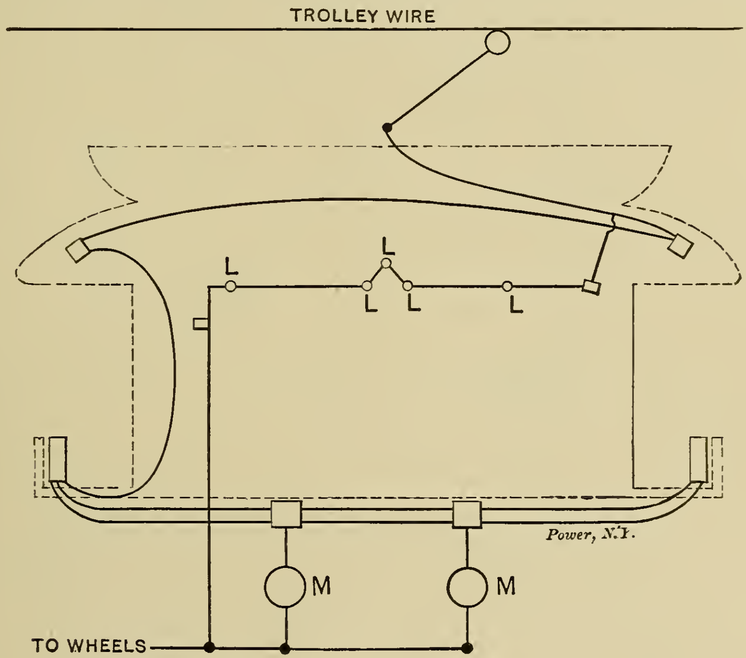

FIG. 82.

bar and — bus-bar are heavy copper rods, to which the dynamos and circuits are connected in parallel. Any number of constant-potential dynamos may thus be worked in parallel, provided they all give the same E.M.F.

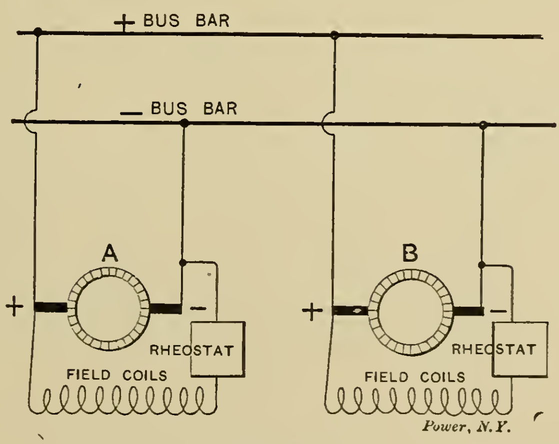

FIG. 83.

Q. 192—Are constant-potential dynamos ever worked in series?
A.—Not strictly in series in the ordinary sense. They are

connected in series, with a third wire, called the "neutral wire," leading out from the connection between the dynamos, as in Fig. 84. Such an arrangement is called the "three-wire system," and is virtually two plain parallel systems combined by consolidating

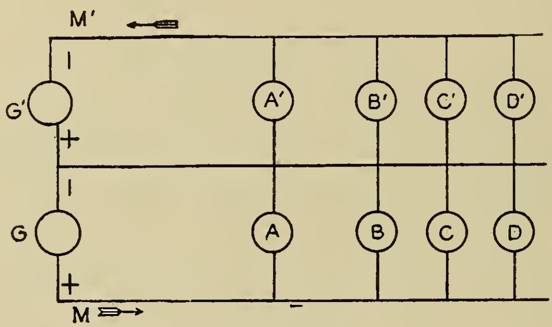

FIG. 84.

one leg of one circuit with one leg of the other circuit. The dynamos are in series so far as the outside wires are concerned, and the wires and lamps constitute a series-parallel system made up of two sub-groups. In the diagram the dynamos are represented by the circles, *G* and G^1. Fig. 85 shows a hydraulic analogue in which pumps and tanks, *P* and *R*, correspond with the dynamos, pipes correspond with the wires and water motors with the lamps. It is evident that water will flow through both groups of motors in series and through both pumps and tanks. Current passes through the dynamos and lamps in the same way.

Q. 193—Why is the third wire in the middle necessary?

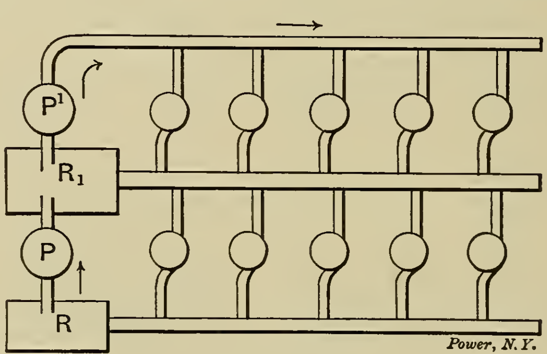

FIG. 85.

A.—To give control of each lamp separately. The lamps could be connected two in series between the outside wires and the middle wire left out; in this case, however, the lamps must be lighted and extinguished in pairs. Such a system has been used, how-

ever, to a limited extent, one 250-volt dynamo being employed instead of two of 125 volts each.

Q. 194—When part of the lamps between the middle wire and one outside leg are cut out, what happens?

A.—The difference between the two pairs of the whole load is taken care of by the neutral wire. In Fig. 86, the generator, G_1, supplies five lamps, while G supplies eight. Assuming $\frac{1}{2}$ ampere per lamp, the wire, M, carries out $2\frac{1}{2}$ amperes, the neutral, N, carries out $1\frac{1}{2}$ amperes, and these two unite and return by way of M_1, which carries 4 amperes. If the neutral, N, were cut and only $2\frac{1}{2}$ amperes were sent through the wires, M and M_1, the 5-lamp group would burn all right, but the 8-lamp group would simply turn dull red. And without the neutral wire it is evidently impossible to get 4 amperes through the big group without pass-

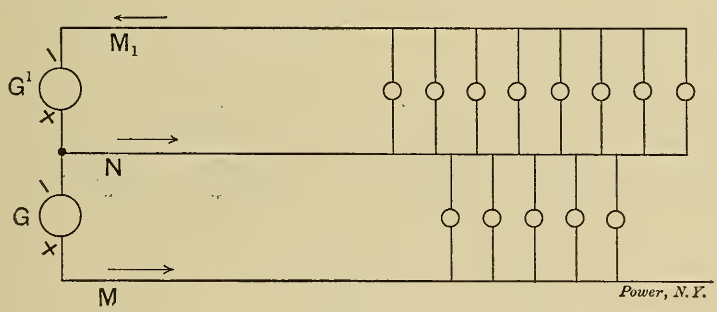

FIG. 86.

ing it also through the small group, which would destroy the lamps of that group.

Q. 195—What regulates the division of the current?

A.—The resistance of the load. The E.M.F. between M and N is maintained constant at the lamps; that between N and M_1 is similarly controlled. Hence, the amount of current flowing between either outside leg and the neutral is determined by the resistance between that leg and the neutral regardless of what exists between the other leg and the neutral. The difference between the current in one leg and that in the other is carried by the neutral.

Q. 196—Are series-wound dynamos run in series or in parallel?

A.—When they are combined on one circuit, which is seldom done, they are connected in series, as shown by Fig. 87. The squares, marked S, are brass plates with taper sockets. Con-

nection between any two sockets is made by a flexible conducting cord, each end of which is attached to a brass plug, fitting snugly in the sockets. The dotted lines indicate the connections made by conducting cords in the diagram, and the arrows indicate the flow of the current.

Q. 197—How are compound-wound dynamos operated together?

A.—Compound-wound dynamos are operated in parallel or on three-wire systems, like plain shunt-wound machines. When operated in parallel an extra connection is necessary, as shown at

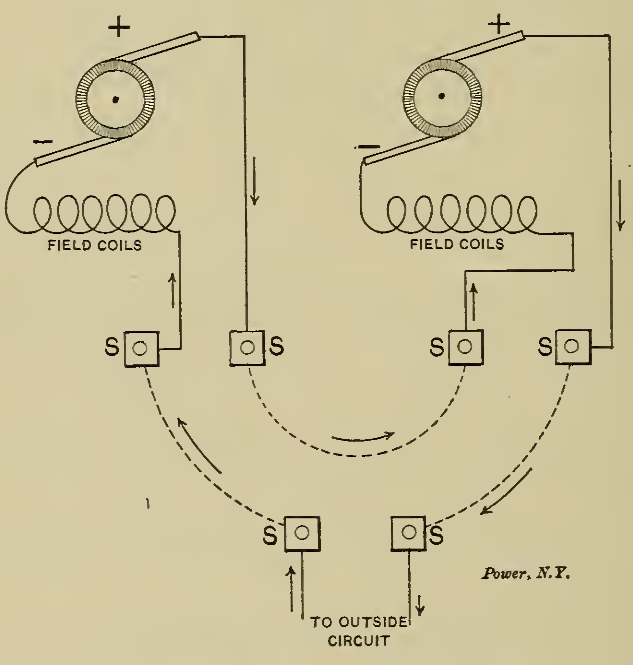

FIG. 87.

E, Fig. 88, allowing current to flow from the brush end of one series coil to the brush end of the other. These connections lead to a bus-bar like the two main bus-bars, so as to avoid manipulation at the dynamos. This bus-bar is called the "equalizer bus-bar."

Q. 198—What is the object of this third connection?

A.—To equalize the current in the series coils of the dynamos. The effect of this connection, electrically, is shown by Fig. 89; it puts the series coils in parallel with each other, so that even if one armature furnishes a little more current than another, the

current divides up evenly between the series coils and strengthens the weaker armature. If this connection were omitted and the

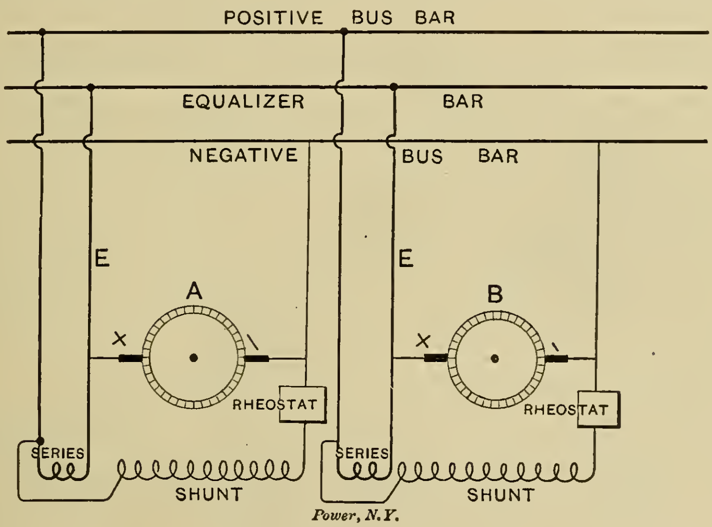

FIG. 88.

shunt fields were unevenly adjusted so that one armature gave more current than the other, this current passing through the

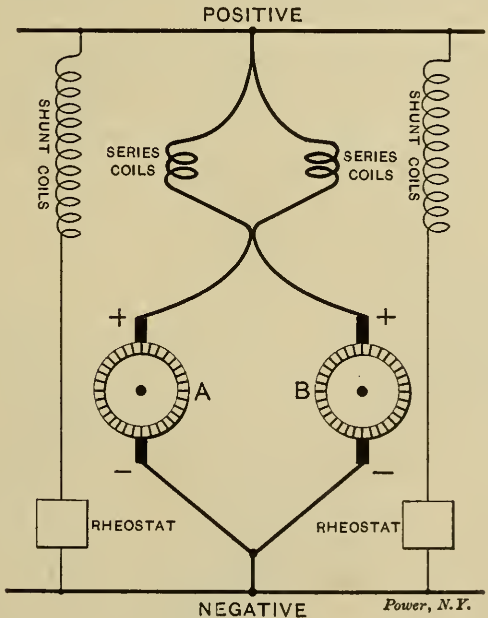

FIG. 89.

series coils of the stronger dynamo would still further increase its strength and throw it still further out of balance with its mate,

or mates. Under these conditions lack of balance is dangerous. (This is explained in the Appendix.)

Q. 199—Why are compound windings used, when they cause extra complication?

A.—Because they increase the E.M.F. of the dynamo as the load increases, and thus make up the "drop" in volts in the armature winding and in the wires between the dynamo and the actual load, doing away with the necessity for regulating by hand every time the load changes. The series coils regulate automatically; when the load increases these coils increase the field magnet strength and raise the E.M.F., and when the load decreases their effect decreases, lowering the E.M.F. again.

Q. 200—What is the "drop" in the armature?

A.—The E.M.F. used up in forcing the current through the wire—the resistance-volts explained under Q. 147 with regard to motors. Suppose a dynamo to be driven at full speed with the work circuit disconnected and a voltmeter applied to the brushes shows 110 volts. Now, if the circuit is closed and a load of, say, 100 amperes results, the E.M.F. at the brushes will not be 110 volts. If the resistance of the armature circuit be $\frac{3}{100}$ of an ohm, then, by Ohm's law, $\frac{3}{100} \times 100$ $(R \times C) = 3$ volts will be used to drive the 100 amperes through the armature circuit, and these 3 volts subtracted from the original 110 leave only 107 volts at the brushes available for outside work. Now, if there is a long stretch of wire between the dynamo and the lamps, and the resistance of this wire is $\frac{1}{25}$ of an ohm, then $\frac{1}{25} \times 100 = 4$ volts will be used up, forcing the 100 amperes through the conecting wires, leaving only 103 volts useful at the lamps. This loss is called "drop," because there is a drop in the electrical pressure from the E.M.F. generated to that available, corresponding to the drop in steam pressure between a boiler and an engine cylinder due to the pipe line. It is in order to make up this "drop" that the field magnet is compound-wound. (See Q. 138.)

Q. 201—How much drop is usually allowed in wires?

A.—From 2 per cent to 10 per cent, according to the conditions. In the wiring within an ordinary building the drop is usually 2 per cent of the maximum E.M.F. of the work circuit. In mills and factories the drop in the mains is $1\frac{1}{2}$ to 2 per cent, and the total

drop is sometimes as high as 10 per cent when water power is used to drive the dynamo.

Q. 202—What are mains?

A.—The wires from which the lamps, etc., are directly fed. Fig. 90 shows a diagram of a simple circuit consisting of one feeder, one main and several taps, marked *t*. The circles represent lamps.

Q. 203—Why are not the lamps, *a*, *b* and *c*, connected directly to the feeder?

A.—Because it is desirable that the voltage shall be as near the

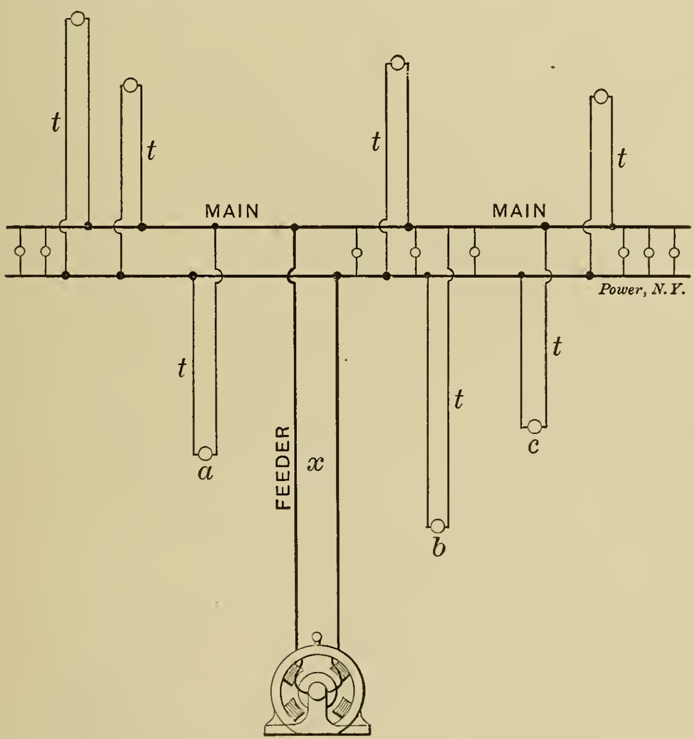

FIG. 90.

same at all the lamps as possible, and the voltage of the feeder at *x* would be higher than that of the main. Moreover, it would confuse the general plan to tap from a feeder, although it is sometimes done. Strictly, a feeder should never be connected with anything between its extremities.

Q. 204—Is there not a drop in voltage in the main?

A.—Yes; the E.M.F. is highest where the feeder connects and lowest at the lamp furthest from this junction, but the difference is not over 2 volts and sometimes only a fraction of a volt.

Q. 205—Does a dynamo supply more than one circuit?

A.—A constant-potential dynamo almost always does. A series-wound, or constant-current dynamo sometimes does. Fig. 91 shows three feeders supplied from one constant-potential dynamo. Fig. 92 shows two circuits supplied from one constant-current dynamo.

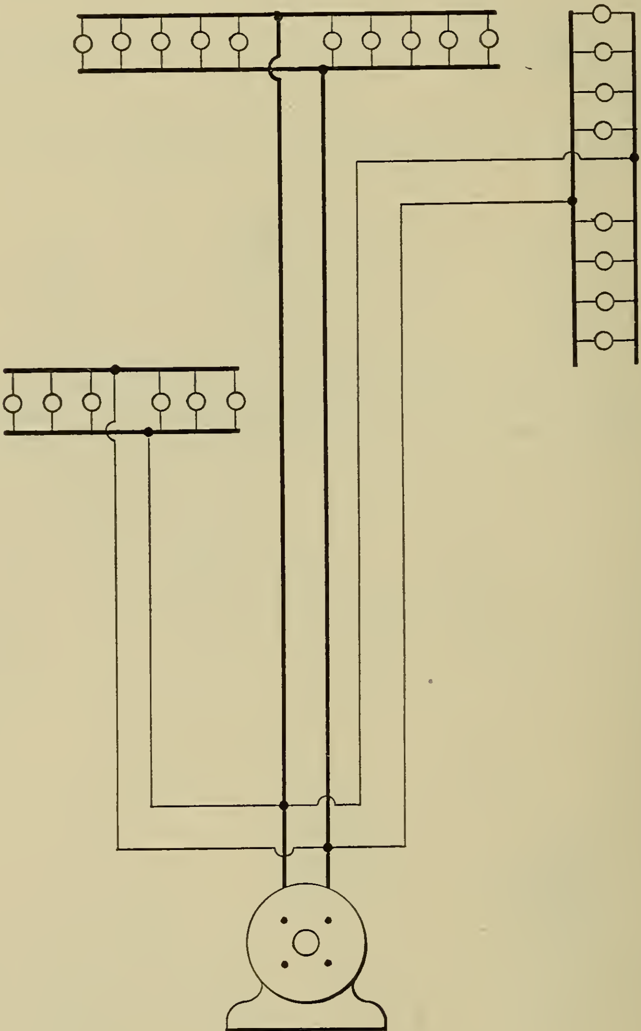

FIG. 91.

Q. 206—In Fig. 91 why could not a single feeder be used for all three mains?

A.—It could be done and occasionally is, but three feeders give better distribution and better control of the circuits. Any one of the three circuits can be cut off at the dynamo without affecting

the other two. If only one feeder served all three mains, the different groups could not be controlled from the dynamo room.

Q. 207—How is the drop in a feeder determined?

A.—By the load, the size of the wire and the feeder length from the dynamo to the main. The drop may be calculated by the following formula, in which *D* represents the distance in feet from end to end of the feeder;* *C*, the current it has to carry; *A*, the

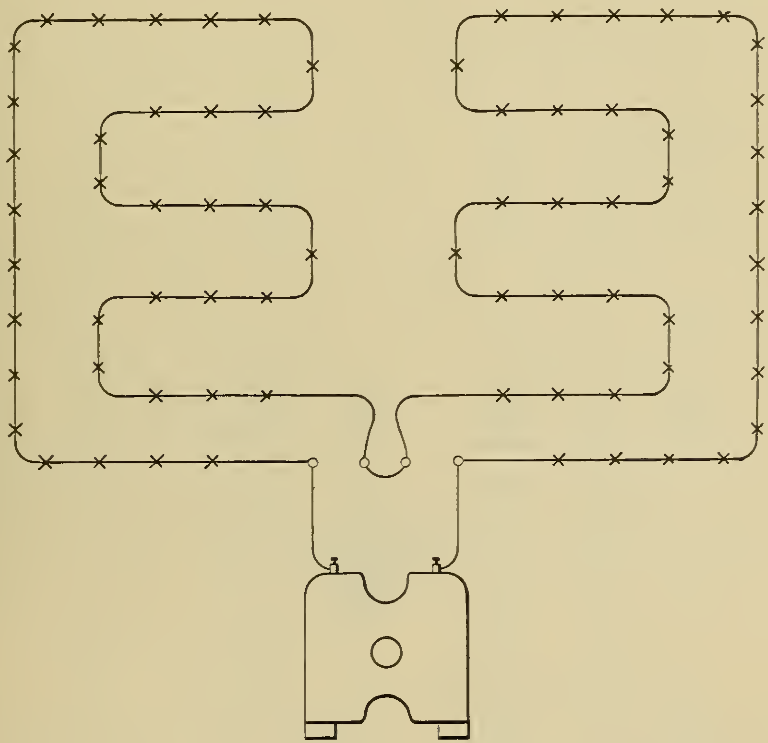

FIG. 92.

cross-sectional area of the wire in circular mils, and *v*, the drop in volts:

$$\frac{21 \times C \times D}{A} = v \quad \ldots\ldots\ldots\ldots\ldots\ldots (24)$$

This formula may be used to find the size of wire necessary for a given load, distance and drop by transposing it into

$$\frac{21 \times C \times D}{v} = A \quad \ldots\ldots\ldots\ldots\ldots\ldots (25)$$

Example.—A feeder 700 feet long from end to end must carry

*The actual length of one leg of the feeder.

a load of 270 amperes with a drop of 2 volts; what is its area in circular mils?

$$C = 270;\ D = 700, \text{ and } v = 2.$$

$$A = \frac{21 \times C \times D}{v} = \frac{21 \times 270 \times 700}{2}$$

which gives 19,845 circular mils as the area. In Table III of

TABLE III

Gauge Number. B&S	Diameter in Mils = $\frac{1}{1000}$ inch. d	Sectional Area in Circular Mils. d^2=C.M.	Weight of Bare Copper Wire per 1000 Feet. lbs.	Resistance of Copper Wire of 98% Conductivity at 89.6° F. 1000 ft. in Ohms.	Safe Carrying Capacity in Amperes. Bare Overhead Wire.	Insulated House Wire.
0000	460	211600	640.5	.050756	620	210
000	410	167805	508.0	.064004	525	177
00	365	133079	402.8	.080704	438	150
0	325	105593	319.6	.101712	369	127
1	289	83694	253.4	.128318	309	107
2	258	66373	201.0	.161812	260	90
3	229	52633	159.3	.204040	219	76
4	204	41743	126.4	.257291	183	65
5	182	33102	100.2	.324441	154	54
6	162	26251	79.46	.409136	130	46
7	144	20817	63.01	.515922	109	38
8	128	16510	49.98	.650526	92	33
9	114	13094	39.64	.820222	77	28
10	102	10383	31.43	1.034580	65	24
11	91	8234	24.93	1.304340	54	20
12	81	6530	19.77	1.744740	46	17
13	72	5178	15.68	2.074000	38	14
14	64	4107	12.43	2.680440	32	12
15	57	3257	9.86	3.297820	27	9
16	51	2583	7.82	4.158120	23	6
17	45	2048	6.20	5.243630	19	5.4
18	40	1624	4.92	1.612080	16	3
Mil.	1	1	.003027149	10740.	.0629	---

wire constants, the nearest size to this is No. 7 wire, with an area of 20,817 circular mils; this size would be used.

Q. 208—Are feeders for three-wire circuits figured out like two-wire feeders?

A.—The outside wires are. The size of the neutral wire is figured on the basis of the maximum difference which may exist

between the loads carried by the two sides of the system under the most extreme probable conditions.*

Q. 209—Why is the three-wire system used instead of the simpler two-wire arrangement?

A.—Because of the greater economy in the cost of the wire. For large plants the conductors must be very large and expensive. Using the three-wire system enables one to use double the voltage, therefore, one-half the current, and, consequently, smaller wires for a given amount of work. For example, if we have 1000 lamps to maintain, of 50 watts each, the total load will be 50,000 watts, or 50 kilowatts. With the two-wire system, even at 125 volts instead of the usual 110, the total current will be $50{,}000 \div 125 = 400$ amperes. ($W = E \times C$; hence, $C = W \div E$). Suppose one feeder 500 feet long carried the load, with $1\frac{1}{2}$ volts drop, its area would be 280,000 circular mils, according to the wiring formula. Now, with three wires, assuming the load to be equally divided, half of the lamps would be in series with the other half, so that the current would be one-half as great as before, or 200 amperes, and the voltage from outside to outside would be 250. If a loss of $1\frac{1}{2}$ volts was allowable at 125 volts, 3 volts is allowable at 250 volts to give the same proportion (percentage) of loss. Then the area of the two outside wires would be

$$\frac{21 \times 200 \times 500}{3} = 70{,}000 \text{ circular mils,}$$

or just one-fourth of the area (and, therefore, the weight) required for the two-wire system. The middle or neutral wire would be given an area about one-half that of each outside wire, so that, in the case assumed, the total area of feed wires would be $70{,}000 + 70{,}000 + 35{,}000 = 175{,}000$ circular mils for three wires, against $280{,}000 + 280{,}000 = 560{,}000$ circular mils for two wires, with the same load and loss. Accurately, the difference would be not quite so great owing to the fact that the load is very seldom divided exactly equally. Under average conditions the feeders and mains will have about one-third the total area for three-wire distribution that they would have for two wires, the load and drop being the same in both systems.

† See Poole's "Electric Wiring" for fuller information.

Q. 210—What is meant by circular mils?

A.—A mil is $\frac{1}{1000}$ of an inch, so that a wire $\frac{1}{4}$ inch in diameter would be 250 mils in diameter. The area in circular mils is found by "squaring" the diameter, or multiplying it by itself. It is sometimes written d^2 and sometimes "circ. mil."

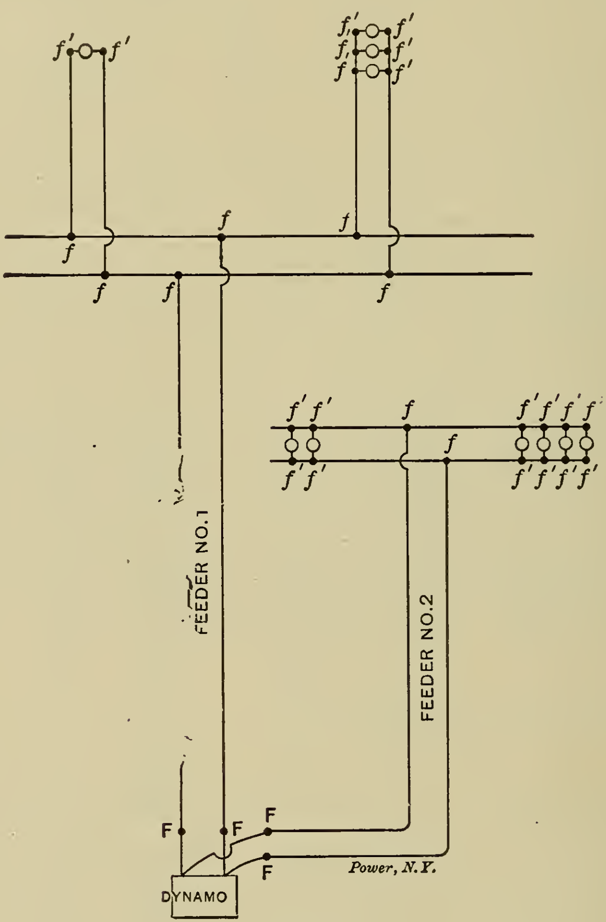

FIG. 93.

Q. 211—What determines the "maximum load allowed," specified in the table?

A.—The maximum allowable load is fixed by the National Board of Fire Underwriters. Passing current through a wire heats it, and the more current the greater the heat; the figures given represent the greatest loads the wires will carry without heating above a safe temperature.

Q. 212—What limits the amount of current in a wire?

A.—The resistance of the complete circuit, of which it forms a part. So long as things are normal the amount of current does not exceed the value intended. Should the opposite legs of a main or feeder or tap become "short-circuited," *i. e.*, connected by a wire of negligible resistance, or brought directly together, an abnormal current would flow. To prevent such a current from continuing long enough to damage the wiring and dynamo, every circuit is provided with a safety device which breaks the connection with the dynamo, and thus cuts off the current, when it becomes too great.

Q. 213—What is this safety device like?

A.—Most safety devices are fuses; sometimes a mechanical de-

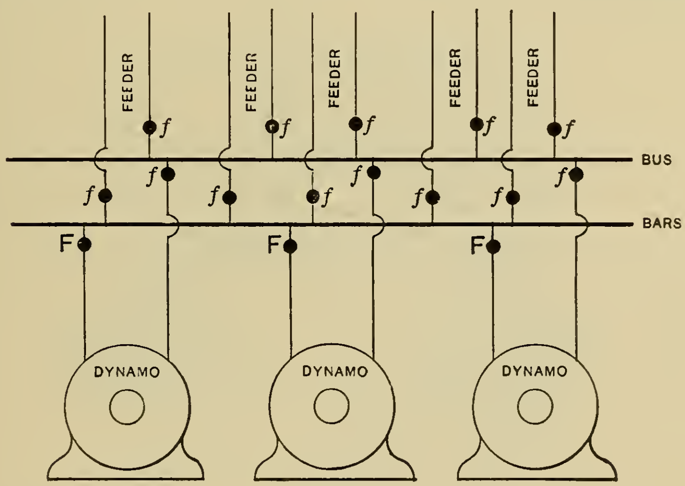

FIG. 94.

vice known as a circuit-breaker is used. A fuse is simply a wire or flat strip of soft metal which melts before the current reaches a point dangerous to other parts of the circuits.

Q. 214—Is a fuse used on each circuit?

A.—Several fuses are used on each circuit. A fuse is inserted in each leg of the circuit at every point where there is a branch, or where the size of the wire changes. In Fig. 93, for example, a fuse would be located at each point marked *F*, *f* and f^1; and each fuse would be of a different size from the others, excepting that all of the f^1 fuses would be alike.

Q. 215—What determines the size of a fuse?

A.—The maximum safe carrying capacity of that part of the

circuit *beyond* the fuse and up to the next fuse. In Fig. 93, the fuses, *F,* in the feeder, near the dynamo, would be capable of carrying the maximum safe current allowed for the size of wire used in that feeder, and the fuses at the far ends would be capable of carrying the safe current allowed for the size of wire used in the main, and so on. When only one dynamo is used, however, the fuse nearest the dynamo must not be large enough to pass a greater current than the dynamo can safely stand, no matter how great the capacity of the feeder may be.

A.—Each dynamo is connected, by "leads," to the bus-bars, and the feeders are led out from these bus-bars. Fuses are inserted between the dynamos and the bus-bars and between the bars and the feeders, as in Fig. 94, the fuses, *F,* in this case being proportioned for the dynamo capacity, regardless of the wiring, and all others being proportioned for the wire capacity.

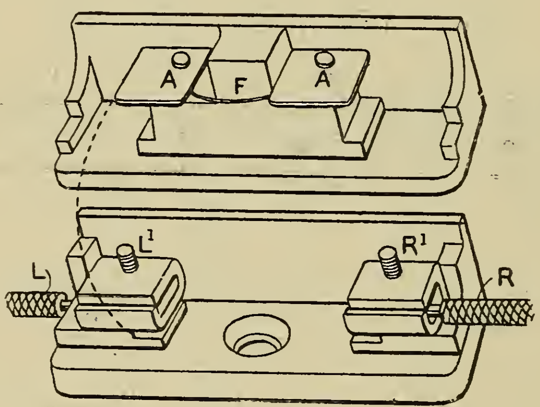

FIG. 95.

Q. 217—How are the fuses connected to the wires?

A.—They are mounted on porcelain or slate insulating bases between heavy brass terminal pieces, to which the circuit wires are attached. The complete arrangement is known as a fuse-block, or cut-out. Fig. 95 shows the simplest and smallest form of fuse-block or cut-out, known as a "bug" cut-out. The ends, *L* and *R,* of the wire are fastened in place by means of set screws, L^1 and R^1, shown in the cut. Those binding screws press together the two sides of a brass clamp, and hold the wire. In the cover of the cut-out at *A, A,* are two plates, also of brass, which fit in under the clamps when the cover is in place, as shown by

the dotted line. These plates are isolated from each other, except for the link of fuse-wire, *F*. Now when the cover is on, the current can pass along from R^1 to L^1, through *F*. *F* is made in accordance with the answer to Q. 215, and therefore there is no danger of overheating the circuit wire. The cut-out is "single-pole," meaning that it contains only a single fuse. Hence, two of them must be used to protect a circuit; one in each leg of the circuit. It is used for very light circuits, such as wall brackets, carrying two or three lamps.

Q. 218—What are cut-outs of larger size like?

A.—In larger cut-outs both fuses are mounted on a single block,

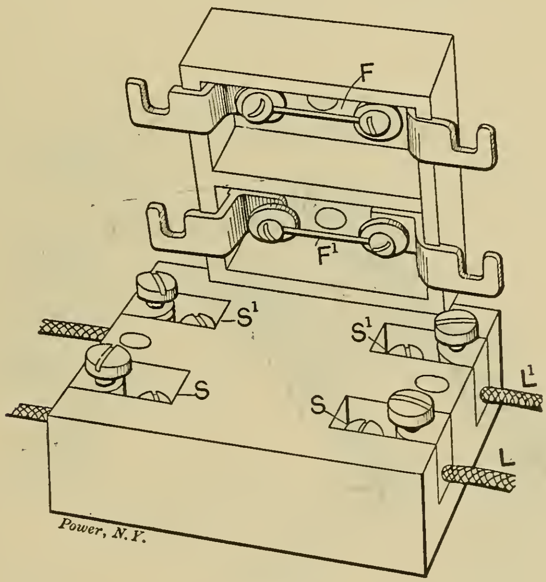

FIG. 96.

as in Fig. 96, which shows a "main line" covered cut-out or fuse-block. In this case, also, the fuses (*F* and F^1) are in the cover, and the manner in which they make the connections should be apparent from the sketch. All of the white portion is porcelain or some other non-conductor, and the dark portions are metal. The main wires being cut, the ends thus formed are run into the holes at the ends, as shown, and fastened in place by means of the binding-screws, *S*, *S*, and S^1, S^1. The other screws are used to secure the cover to the base, and at the same time secure good connection between the ends of the wires and the fuse clips. For branches or taps, at right angles to a main, the style of block

shown by Fig. 97 is used; this is known as a "branch block." The principle is the same as in the last case, but the main wires are not cut at all. They (L and L^1) are led through the channels shown in the base, and secured to the binding posts, S and S^1. The branch wires, B and B^1, terminate at the holes in the end of the cut-out base, where they are secured by the inner binding screws. The fuses are at F and F^1. The dark portions being conductors and the light parts being non-conductors, it will be seen that as far as the branch circuit is concerned, the result obtained is the same as if the wires were connected direct, as in Fig. 90.

Q. 219—How are the fuses arranged in a series circuit?

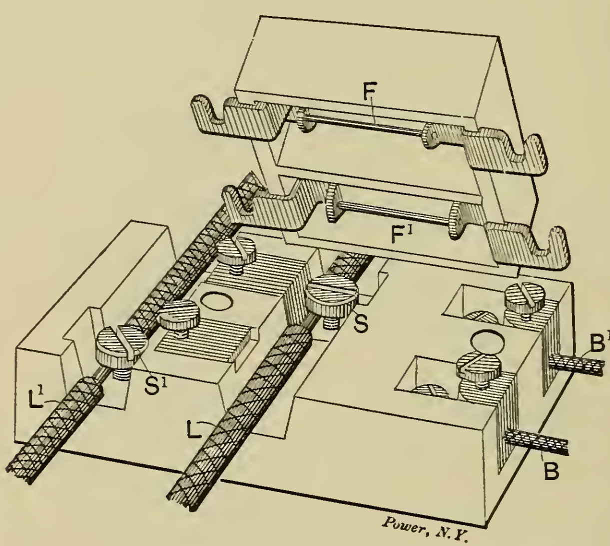

FIG. 97.

A.—Fuses are not used on constant-current systems. They are not needed, because the current is maintained practically at one value all the time, either by the dynamo itself or by an automatic regulator.

Q. 220—When a fuse melts what is done?

A.—The circuit is disconnected from the system and a new fuse is put in the block. Then the circuit is re-connected. If the fuse blows (melts) again, the trouble on the circuit must be removed before the circuit is reconnected.

Q. 221—How are the wires placed in a building?

A.—Sometimes on the surface of the ceiling and walls, but more generally between floor and ceiling and inside the walls. The two

classes of wiring are known as surface wiring and concealed wiring. Surface wiring is divided into two sub-classes, namely, cleat wiring and molding work.

Q. 222—What is cleat wiring?

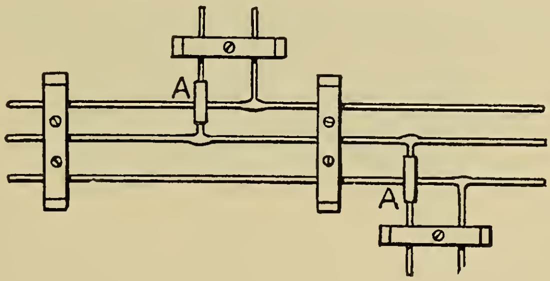

FIG. 98.

A.—An installation in which the wires are fastened to the walls and ceilings at intervals by cleats, as in Fig. 98, which shows a little stretch of three-wire mains, from each side of which two-wire

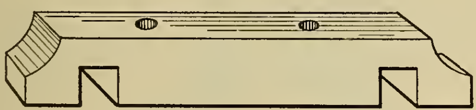

FIG. 99.

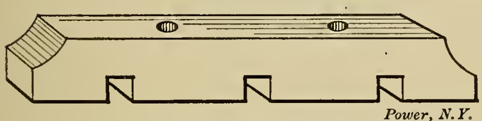

FIG. 100.

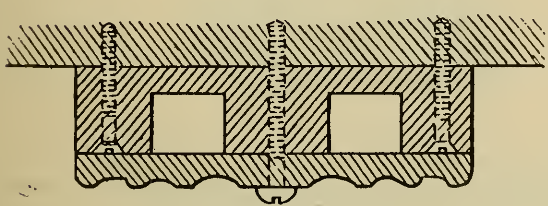

FIG. 101.

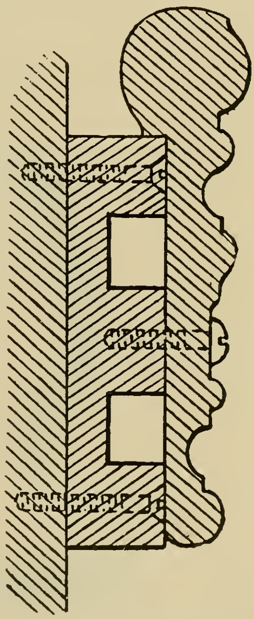

FIG. 102.

taps or branches are led. Where one wire crosses another an extra insulation must be used, as at *A, A*. This may be a piece of rubber tubing or a heavy coating of tape. Figs. 99 and 100 show a two-wire and a three-wire cleat, respectively.

Q. 223—What is molding work?

A.—Wiring placed in grooved molding. Fig. 101 is an end view of one form of two-wire molding for ceilings and side walls, and Fig. 102 is a form of side-wall molding. Fig. 103 shows a

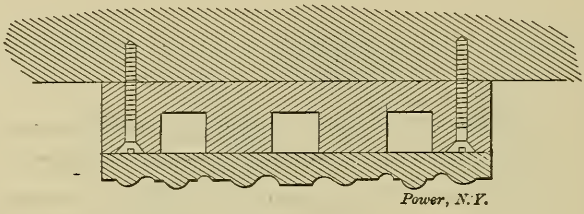

FIG. 103.

three-wire molding corresponding with Fig. 101. These moldings come in long strips. There are two parts, the "backing" containing grooves for wires, and the "capping," used to cover the grooves. The backing is fastened to the ceilings, walls, or floors by countersunk screws, as shown in the figures, and the capping is fastened to the backing by means of round-headed brass screws.

Q. 224—How is concealed wiring arranged?

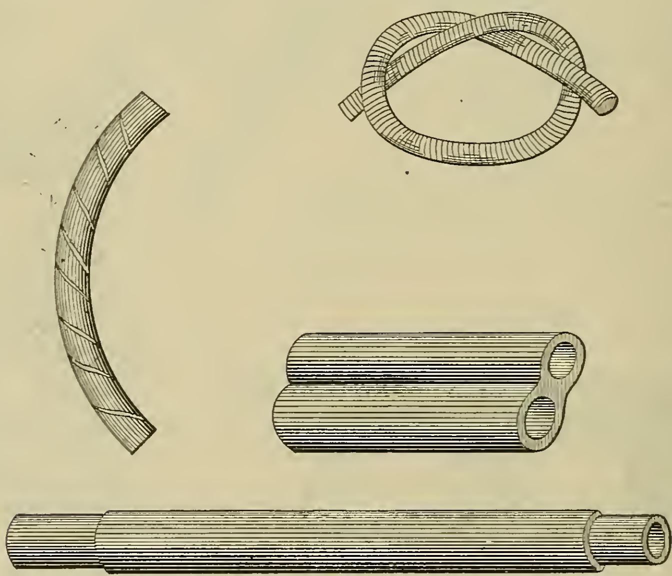

FIG. 104.

A.—The wires are sometimes secured to porcelain knobs, where they run parallel with joists and beams, and run in porcelain tubes through the beams when the latter are of wood and at right angles to the wires. In most modern buildings, however, the wires are

run in tubes of insulating material, or metal tubes with insulating linings, some rigid and some flexible; sections of both kinds are shown in Fig. 104. Such a system is called conduit wiring.

Q. 225—What are the conditions determining the system of wiring to use?

A.—Cleat wiring is used wherever appearances make no differ-

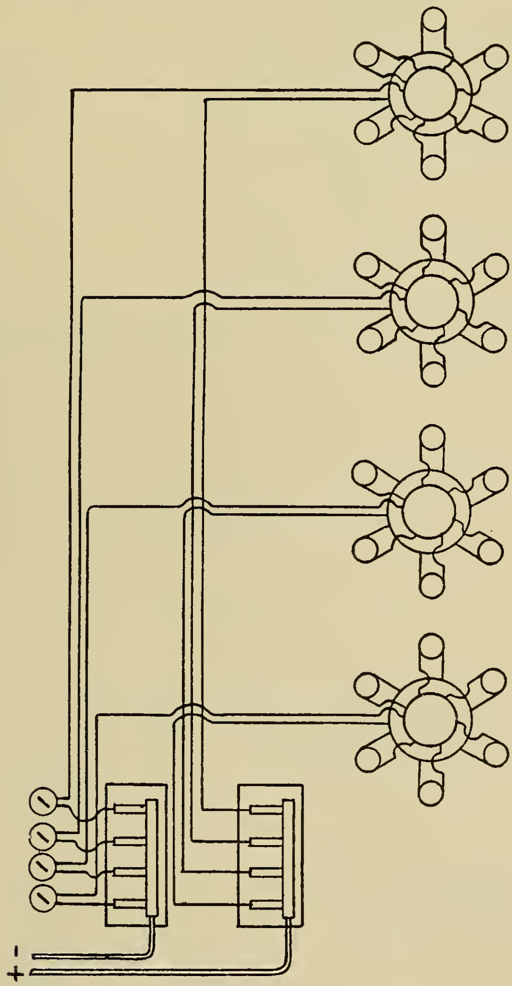

FIG. 105.

ence and the surrounding atmosphere is thoroughly dry, as in most mills, factories, plain storerooms, etc. It is the cheapest to install and easiest of access. Molding work comes next in point of cost and easy access, and is used where the molding is not considered disfiguring and the surroundings are dry. It must not be used in damp places because the wood absorbs moisture and leakage is liable to result. In finely finished buildings con-

cealed wiring is always used; if the building has a wood frame the wiring is sometimes put on porcelain, but the conduit system is much preferable because of the greater protection to the wires, and because the conduits can be put in while the building is being

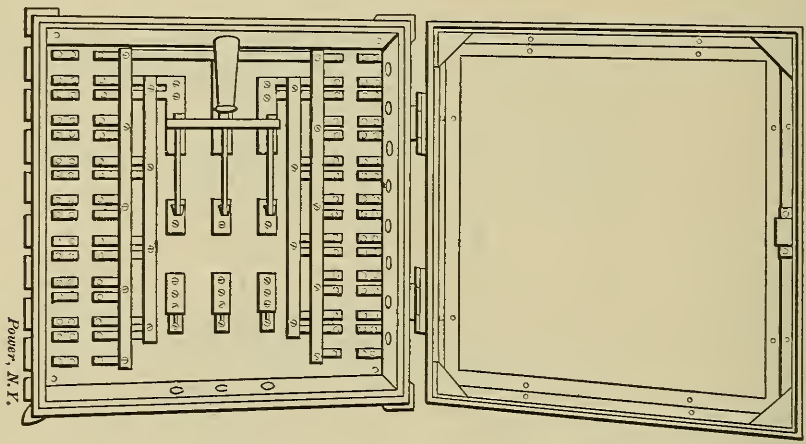

FIG. 106.

erected and the wires can be drawn through afterward. In iron frame buildings the conduit system is imperative if the wiring is to be concealed.

Q. 226—How are fuses replaced in concealed wiring, if they blow?

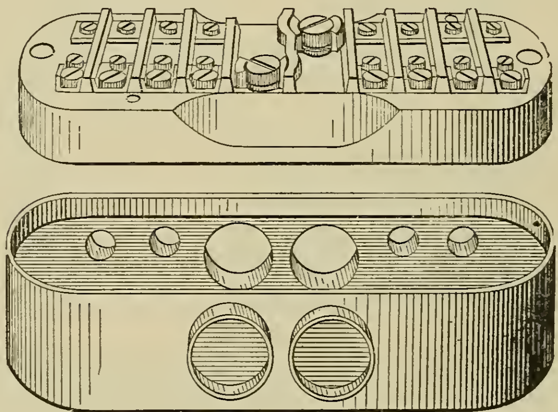

FIG. 107.

A.—The lamps are divided up into little groups, each having a separate feeder. All the feeders run from one point, where the fuses are located on a composite fuse-block called a tablet board. This is put in a little closet set in the wall. The switches for the

feeders are usually put in the same closet. Fig. 105 shows four groups of lights fed from a tablet board, and Fig. 106 is a typical distributing closet with tablet board and main switch.

Q. 227—Are not branch circuits ever used in concealed work?

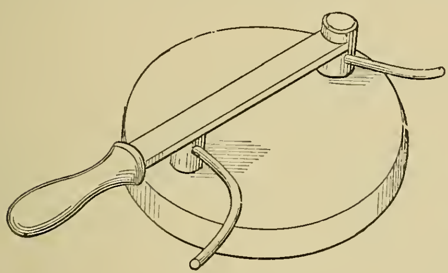

FIG. 108.

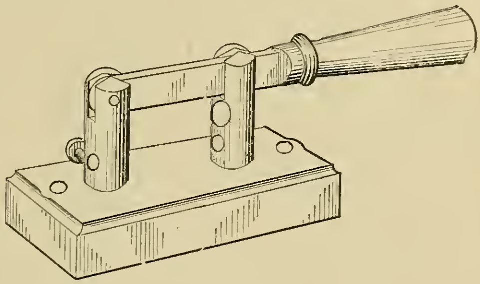

FIG. 109.

A.—When the wiring for a small load is distributed over a large area branch circuits are put in. In such a case a "junction box" is set in the wall, like the closet, and the ends of the branches lead into it. Fig. 107 shows a "junction box" and its tablet block. The holes in the sides of the box have projecting flanges to which the ends of insulating tubes are fitted watertight. The main wires are bared and held under the large screws in the center of the fuse block and the ends of the branch wires are held under the smaller screws. Fuses go across between the pairs of very small screws and are separated by ribs of porcelain on the base.

Q. 228—How is a circuit connected and disconnected?

A.—By means of switches. Fig. 108 shows a switch for breaking a single conductor; Fig. 109 shows another form designed for heavier currents, and Fig. 110 is a diagram of the connections.

Q. 229—Why is the switch in Fig. 109 better for heavy currents than that in Fig. 108?

A.—Because the contact between the lever and the terminal has

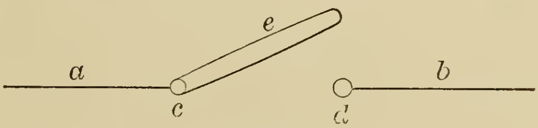

FIG. 110.

more area and the parts can be pressed more firmly together.

Q. 230—Have these switches distinguishing names?

A.—Yes. Fig. 108 shows a single-pole button switch and Fig. 109 a single-pole knife switch. Both of these are single-break,

meaning that the circuit is broken at one point only. Fig. 111 shows a single-pole double-break switch; the diagram for this is shown by Fig. 112.

Q. 231—What is the object of having a double break?

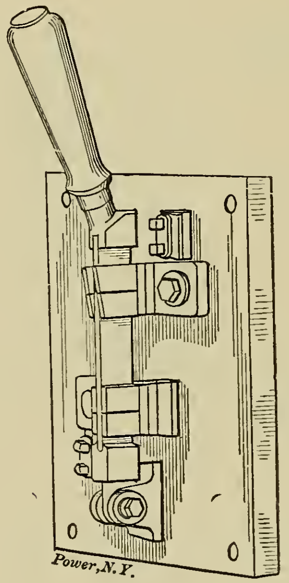

FIG. 111.

A.—In order to divide the flash into two parts. When a circuit is opened the current follows across the break until the opening is so wide that the E.M.F. will not force the current across. If the circuit is opened at two points in series at the same instant, the E.M.F. is divided between the two breaks and the length to which it will maintain a flash at either break is reduced to one-half. Another reason for providing two breaks is to avoid using the switch-blade pivots as conductors, the contact between the pivots and the blades being too loose for good conductivity.

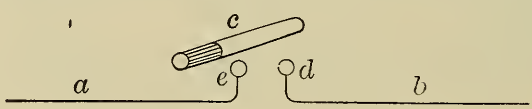

FIG. 112.

Q. 232—Are switches ever made with more than two breaks?

A.—No; a multiplicity of breaks would complicate the construction tremendously. Moreover, it is almost impossible to make several contacts separate at precisely the same instant, and unless

they did so the value of a multiple break would be largely reduced. For very heavy circuits "quick-break" switches are used. Fig. 113 represents a single-break switch of this type. The contact blade is held between the jaws by their clamping friction until

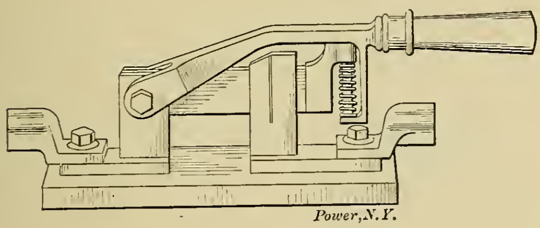

FIG. 113.

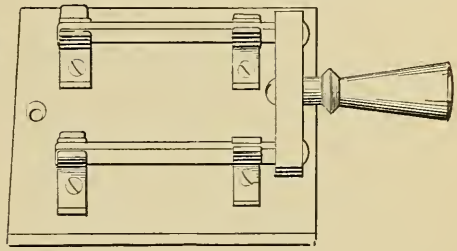

FIG. 114.

the handle compresses the spring sufficiently to force the blade out; as soon as it leaves the jaws, the spring expands and drives it away from the jaws with far greater rapidity than the hand

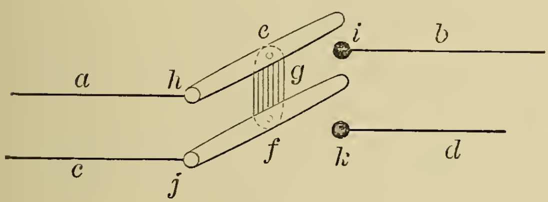

FIG. 115.

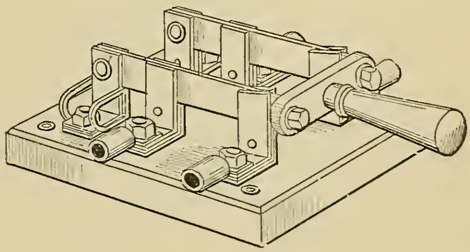

FIG. 116.

could possibly do it, thus reducing the duration of the flash to a very small fraction of time.

Q. 233—Are switches put in both legs of a circuit, like fuses?

A.—Yes; double-pole switches are universally used for two-

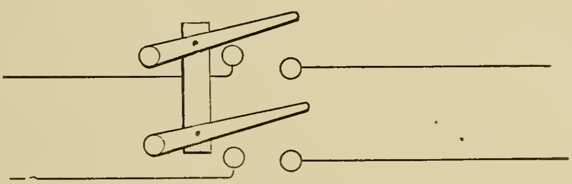

FIG. 117.

wire constant-potential circuits. Fig. 114 illustrates the single-break double-pole form, of which Fig. 115 is the diagram. Fig. 116 is the double-break, double-pole switch, of which Fig. 117 is the diagram. For three-wire circuits, three-pole switches like

Fig. 118 are used; Fig. 119 is the corresponding diagram. These are also made with a double-break in each pole or leg, like the single-pole and double-pole switches already shown.

Q. 234—What are the thumbscrews on the base for?

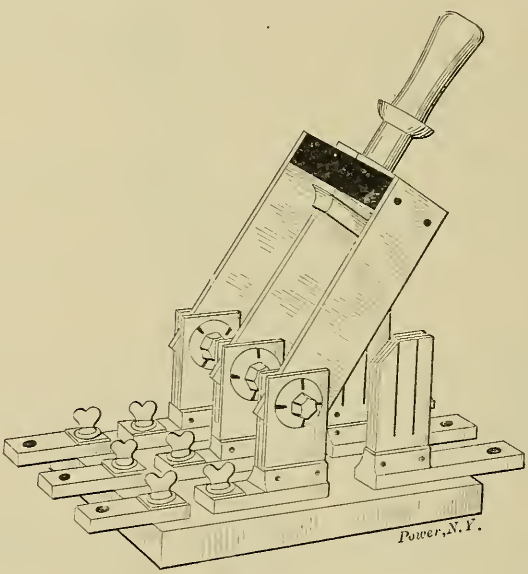

FIG. 118.

A.—To hold fuses; this switch is a combined switch and fuse-block on a single base. This form is frequently used in small plants.

Q. 235—Are there any other kinds of switches?

A.—There is one more general class, known as the double-throw

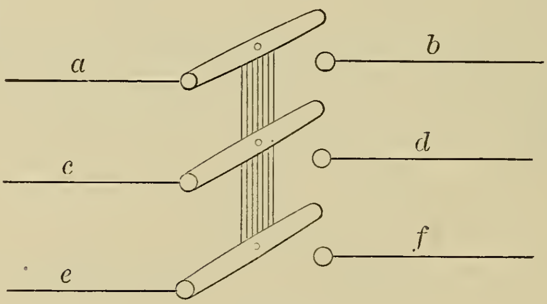

FIG. 119.

switch. Whenever it is desirable to open one circuit and immediately close another, or to transfer one or more connections from one circuit to another in the least practical interval of time, a double-throw switch is used. Also, when one connection is to be

broken and another closed, and it is undesirable to allow both to be closed at the same time, a double-throw switch is used. Fig. 120 illustrates the single-pole double-break form, and Fig. 121 is its diagram of connections. Fig. 122 is the double-pole single-break

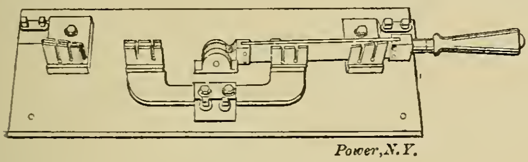

FIG. 120.

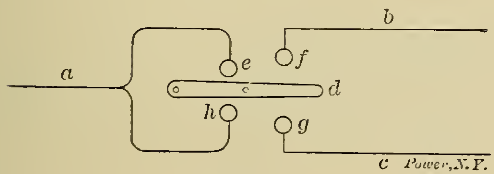

FIG. 121.

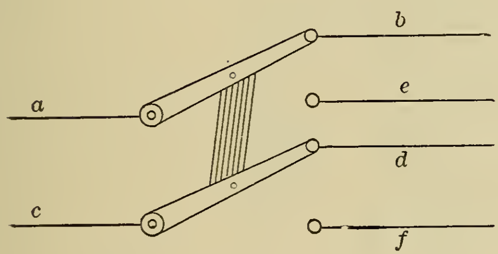

FIG. 123.

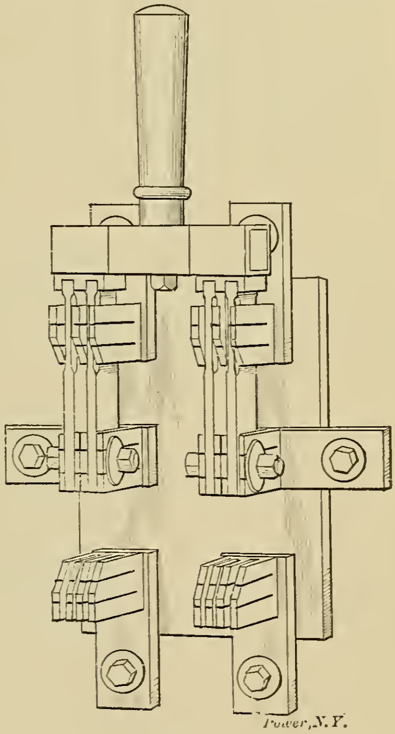

FIG. 122.

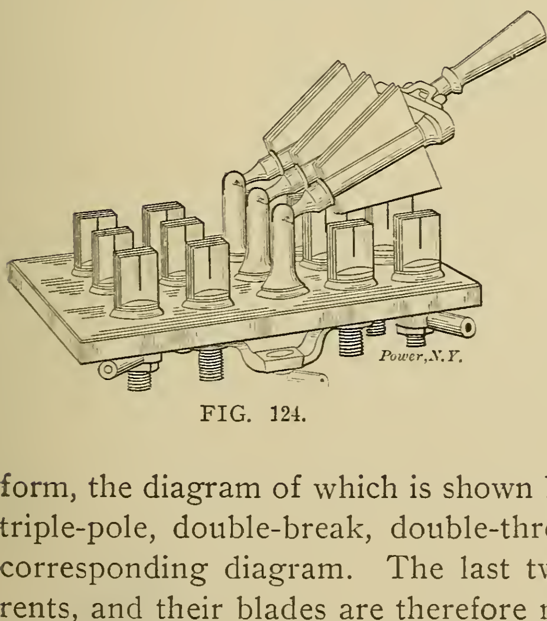

FIG. 124.

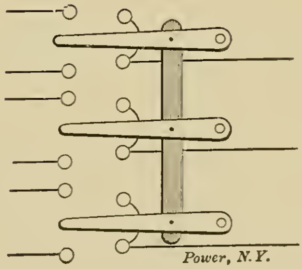

FIG. 125.

form, the diagram of which is shown by Fig. 123. Fig. 124 is the triple-pole, double-break, double-throw switch; Fig. 125 is the corresponding diagram. The last two are for very heavy currents, and their blades are therefore made up of several strips to give greater contact area in the jaws.

Q. 236—How are the switches and fuse-blocks arranged in a dynamo room?

A.—They are all grouped on marble or slate slabs, held in a vertical position either by braces from the wall or by legs, or both. The complete arrangement is called a switchboard. Fig. 126 shows a small switchboard for two dynamos. Beginning at the top of the board, there are three indicating instruments; the central one is a voltmeter, to show what the E.M.F. is and the other two are ampere-meters, or ammeters, each indicating the output

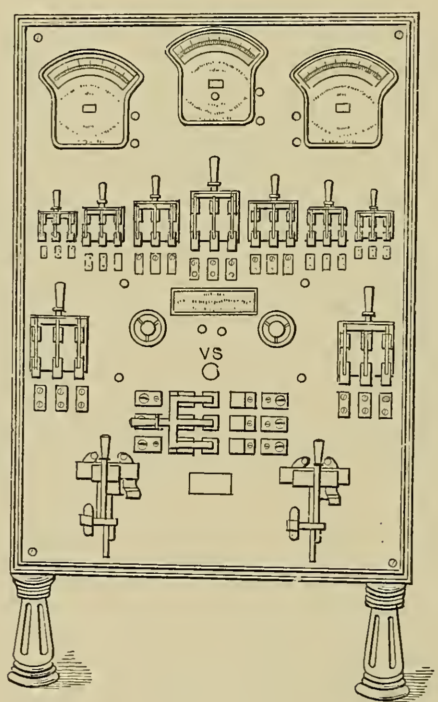

FIG. 126.

of its dynamo in amperes. Immediately below the instruments is a row of feeder switches which serve to connect and disconnect the various feeders with and from the bus-bars, which are mounted behind the board. Next comes the name-plate in the center, and on each side of its lower edge are the rheostat hand-wheels; the rheostats are behind the switchboard and the hand-wheel stems pass through it. The two large switches near the edges of the switchboard are the dynamo switches, connecting the dynamos with the bus-bars. At *vs,* below the name-plate, is a knob which works a rotary switch on the back of the switchboard. This

switch is called the voltmeter switch because it serves to connect the voltmeter with various parts of the system, so that the E.M.F. at any important point may be instantly ascertained by the attendant. Immediately below the voltmeter switch is a double-throw switch, the function of which is to transfer the bus-bars from connection with the dynamo switches to one with some other source of current, such as a street circuit, in the event of a failure of the dynamo or engine. At the bottom are two automatic switches, called circuit breakers.

Q. 237—What are circuit breakers?

A.—Mechanical devices, used instead of fuses, to open a circuit when the current goes beyond a certain value. The usual form is a knife-blade switch (either single-pole or double-pole, according

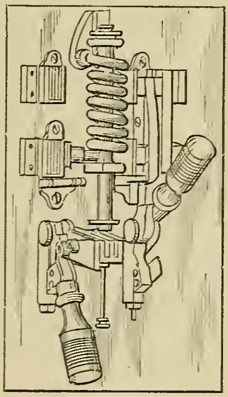

FIG. 127.

to requirements) normally held shut by a latch and provided with a strong spring which tends to open the switch. A magnet is also provided which releases the latch and allows the spring to throw the switch open as soon as the current reaches the point for which the magnet and latch are adjusted. Fig. 127 shows a double-pole circuit breaker in which two separate knife-blade switches are used. The more common form has the blades coupled together by an insulating cross-bar, exactly like a hand switch. The magnet is a solenoid consisting of a few turns of heavy wire; its plunger trips the latch.

Q. 238—Why are circuit breakers used instead of fuses?

A.—For two reasons. First, because they are more sensitive, and can be adjusted to open precisely at a given current value,

just as a safety valve opens at a given steam pressure. Secondly, because it requires much less time to reset a circuit breaker than to replace a fuse.

Q. 239—Why are not circuit breakers used entirely in place of large fuses?

A.—In some plants they are; no fuses are used on any part of the switchboard. The only reason they are not always substituted for large fuses is that they are vastly more expensive in first cost. For the same reason and also because small fuses are more reliable and less objectionable than large ones, circuit breakers are scarcely ever used instead of small fuses.

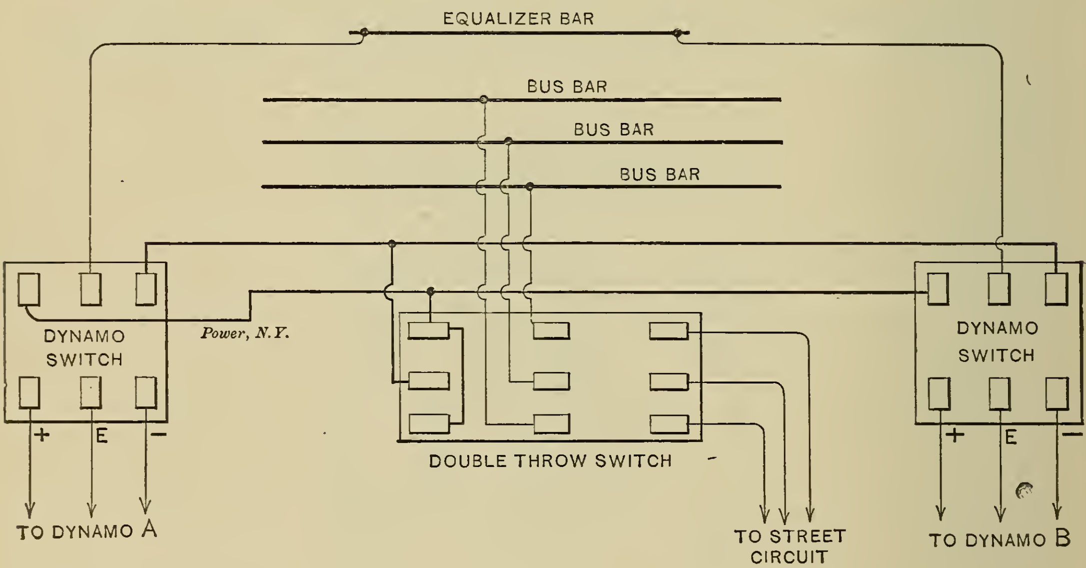

FIG. 128.

Q. 240—In Fig. 126 why are the dynamo switches triple-pole?

A.—The dynamos are operated in parallel, and the middle blade connects the equalizer wire, *E*, Fig. 88, with the equalizer bar. See also Fig. 128.

Q. 241—Why are triple-pole feeder switches used?

A.—Because the wiring is laid out on the three-wire plan. This switchboard is the type used for large buildings having their own electric plants. In such buildings the wiring is customarily put in on the three-wire plan, so that when necessary it may be thrown on to the Edison three-wire street circuit. When supplied from the house dynamos, however, it is connected on the two-wire plan by connecting the outside legs together and putting the two sides

of the system in parallel. The double-throw switch just above the circuit breakers accomplishes this, as shown by the diagram, Fig. 128.

Q. 242—If two dynamos are to be used why are they not connected on the three-wire plan to save wire?

A. Because the load is so small during about three-fourths of each day that only one dynamo is necessary, the two being run together only during the period of heavy load, which does not exceed five or six hours a day.

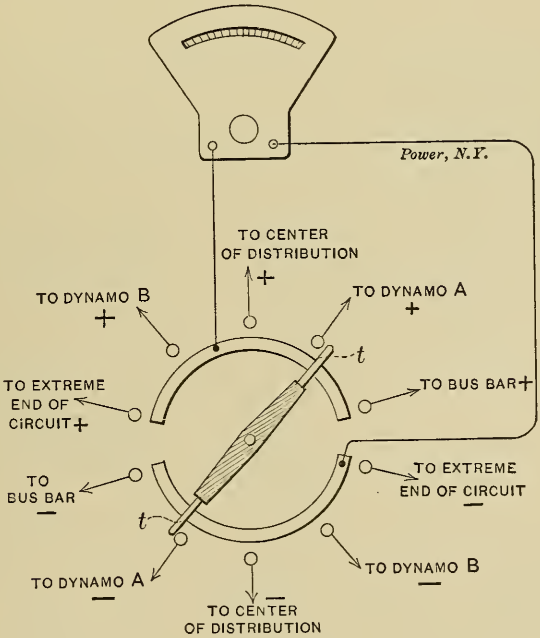

FIG. 129.

Q. 243—How is the voltmeter switch arranged and why is it necessary?

A.—The connections are as shown by Fig. 129, from which it is evident that the voltmeter can be connected with the terminals of either dynamo, or with the bus-bars, or with either a central point or remote point in the lamp circuits. Under ordinary conditions it remains connected to the circuit at the central point of distribution. When one dynamo is already in circuit, however, and it becomes necessary to connect up the other one, it is imperative that the E.M.F. of the added machine shall be *exactly* the same as the E.M.F. at the bus-bars. Hence, the connections to dynamo terminals and bus-bars, which enable the attendant to

compare the voltage at both before closing the dynamo switch. All the + connections are on one side of the circle swept by the switch and all the — connections are on the other side.

Q. 244—Why must the E.M.F. of the added dynamo be exactly the same as the bus-bar voltage before it is thrown in?

A.—To avoid forcing current backwards through one of the dynamos. If dynamo *A*, Fig. 83, is supplying the circuit, the bus-bar E.M.F. being 120 volts, and dynamo *B* is thrown in circuit with an E.M.F. of 115 volts, dynamo *A*, being 5 volts stronger, will

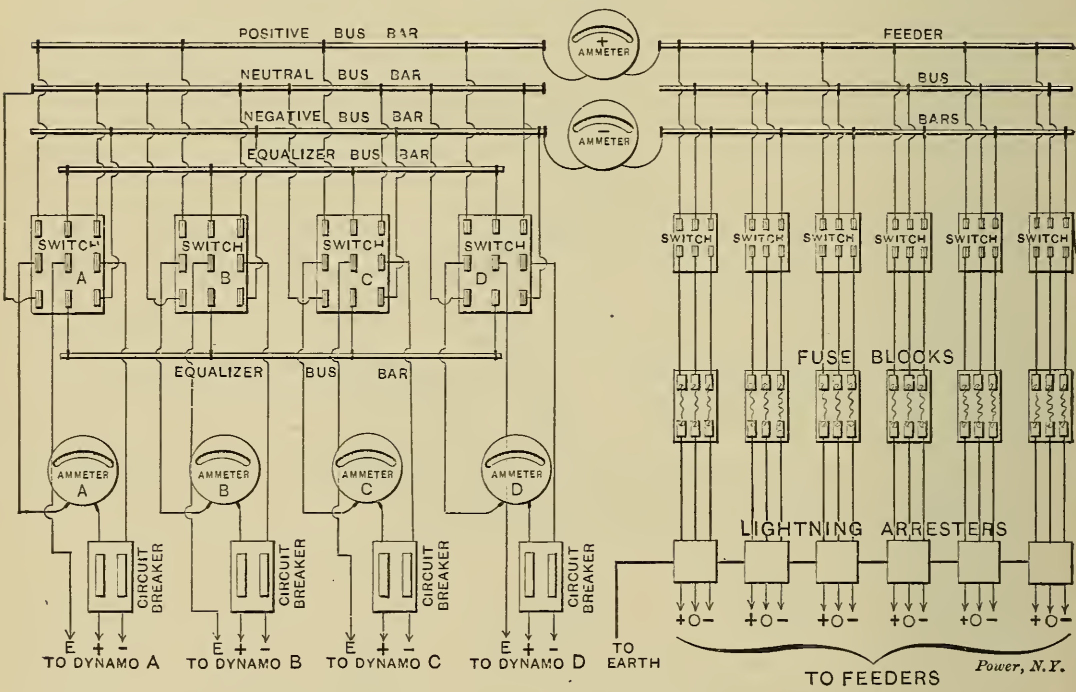

FIG. 130.

force current backward through dynamo *B*. The result will be the same as though dynamo *B* were lying idle and subjected to an E.M.F. of 5 volts, generating none in opposition. If the resistance of the two dynamo armatures and the intermediate connections were $\frac{4}{100}$ of an ohm, the current flowing between them would be

$$C = \frac{E}{R} \qquad \frac{120}{0.04} = 3000 \text{ amperes.}$$

Q. 245—Would not such a heavy current throw the circuit breakers and protect the dynamos?

A.—The circuit breakers would be thrown, but in the brief in-

stant required for the magnet to act a heavy strain would be inflicted upon both dynamos, which might result in damage.

Q. 246—How does the switchboard shown in Fig. 126 differ from one used in a central station.

A.—In the arrangement for transferring the circuits to some other source of current and the manner of working the dynamos. In a central station the dynamos would most likely be operated on the three-wire plan, and if more than two were used they would be

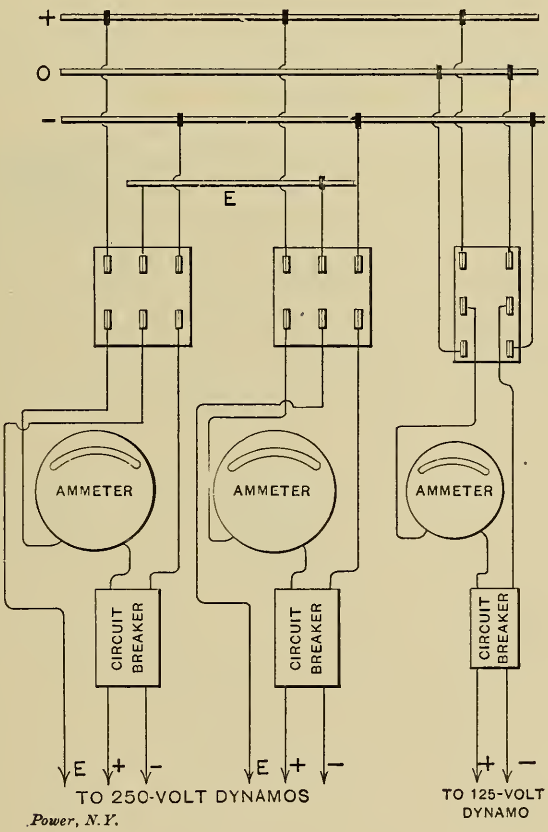

FIG. 131.

arranged to work in parallel on each side of the system. Fig. 130 is a diagram of switchboard connections for a three-wire central station where four dynamos, all of equal size and voltage, are used. The equalizing wires are marked *E*. The voltmeter and its switch are omitted.

Q. 247—Why are double-throw dynamo switches used?

A.—So that each dynamo may be connected to either side of the

system. When the switch is left in its middle position the dynamo is disconnected entirely.

Q. 248—Why are so many ammeters necessary?

A.—The individual ammeters are needed to show the load on each dynamo. The ammeters marked + and — show the total output on each side of the system.

Q. 249—Are three-wire systems always arranged as shown in Fig. 130?

A.—No; an arrangement sometimes used is shown by Fig. 131. The main dynamos are 250-volt machines, and any difference between the loads on the two sides of the system is taken care of by a smaller 125-volt dynamo, which can be put on either side of the neutral wire, as occasion requires.

Q. 250—In Fig. 130 the feeders are represented as passing out through lightning arresters. What are they?

A.—A lightning arrester serves to prevent the lightning from damaging the dynamos and other apparatus by diverting it from the circuit wires into the earth—"side-tracked" it, so to speak. Lightning nearly always takes the nearest path (electrically) to the earth, and by providing a side path from the circuit directly to the earth it is drawn off.

Q. 251—Does not the side path connect the circuit to the earth?

A.—No. Fig. 132, which illustrates the principle of lightning arresters, will show why. A toothed brass plate, *c*, is connected to the circuit wire and another one, *d*, just like it, is connected to the ground. The gaps between the teeth of the plates are very small, and while the regular working current will not jump across, lightning, which is electricity of enormous E.M.F., will do so readily. Hence, when lightning comes in on the line wire, *A*, as soon as it reaches the arrester it jumps over to the ground terminal, as *d* is called, and goes to the earth. In order to make the path as good as possible, a large metal plate, *G*, is buried in the ground deep enough to be in moist earth and connected to the ground terminal, *d*.

Q. 252—Is this arrester used in electric light and power stations?

A.—No; it is only used in telegraph and telephone work where very weak currents are employed. It forms the basis of all gap lightning arresters, however, and for this reason is described here.

The heavy duty arresters are based on the same principle, but the construction is different. When heavy currents are used the dynamo current will follow the lightning across the gap and establish an "arc" or continuous flame from one plate to the other, de-

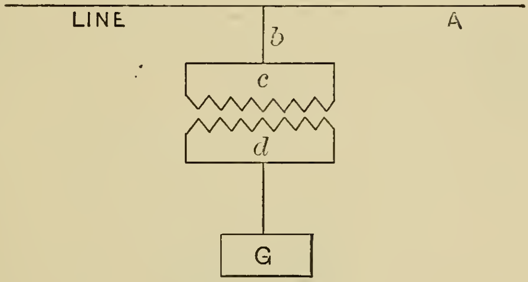

FIG. 132.

stroying the plates and causing other more serious damage. Hence, lightning arresters used on heavy duty circuits are designed to rupture the arc the instant it is formed.

Q. 253—How is the arc ruptured?

A.—There are three general methods; the oldest consists of

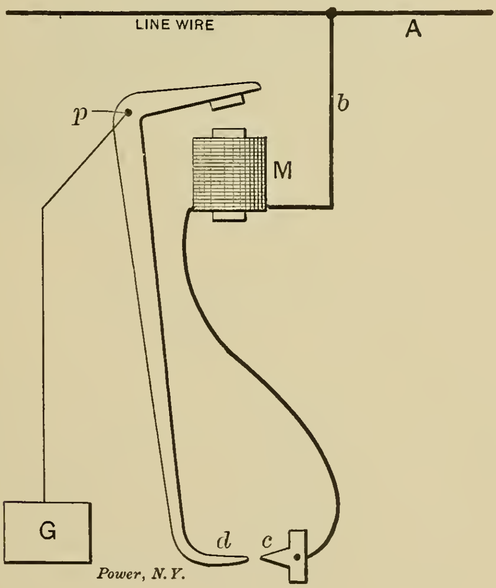

FIG. 133

separating the plates or terminals of the arrester, the increased resistance thus obtained serving to break the flow of current across the gap. The next oldest is the magnetic blow-out and the latest type is called the "non-arcing" arrester, in which the terminals

are made of a peculiar alloy that will not give off the vapor necessary to maintain an arc. Figs. 133 and 134 show two arresters of the first class. In Fig. 133 the ground terminal, *d*, is on the end of a long arm pivoted at *p*. When lightning passes across the

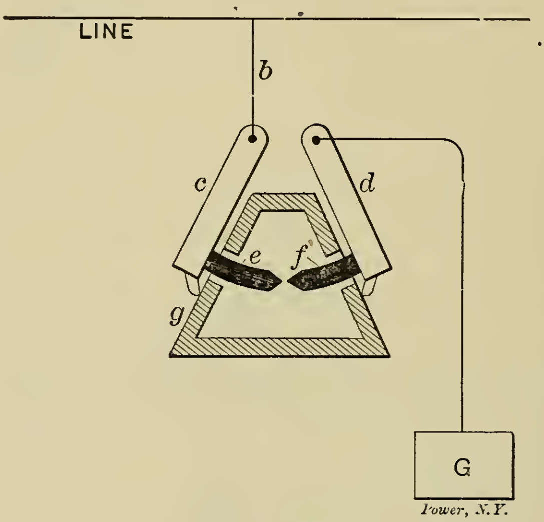

FIG. 134.

gap the dynamo current follows it and energizes the magnet, *M*, which instantly jerks the arm away from the line terminal and breaks the arc. The arm then falls back again, ready for the next flash. In Fig. 134 both of the terminals (*e* and *f*) are placed on pivoted arms, *c* and *d*, and project into the side of a small box, *g*.

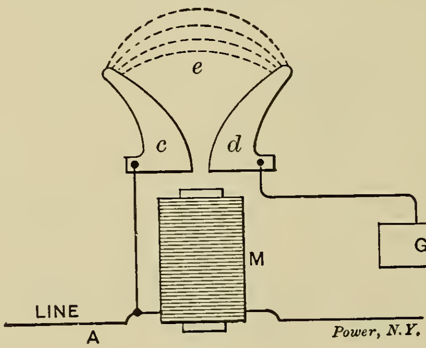

FIG. 135.

When the arc is established between the points, *e* and *f*, which are of carbon, an intense heat results and an expansive vapor is liberated; the hot air in the box expands, and, with the vapor, forces the terminals out of their holes and breaks the arc.

Q. 254—Why does not the flame burn off the ends of the carbons?

A.—It does, and on this account the arrester has to be adjusted frequently to keep the carbons near enough to each other.

Q. 255—How do the other arresters work?

A.—The magnetic blow-out is illustrated by Fig. 135. Its action is similar to that of a strong air blast. A magnet will repel an electric arc, and in this arrester a powerful magnet, *M*, is arranged with its poles close to the terminal plates, which curve apart, as shown. When the lightning draws the dynamo current across, the magnet drives the flame away from it to the extremities of the terminal plates, as at *e*, which are so far apart that the

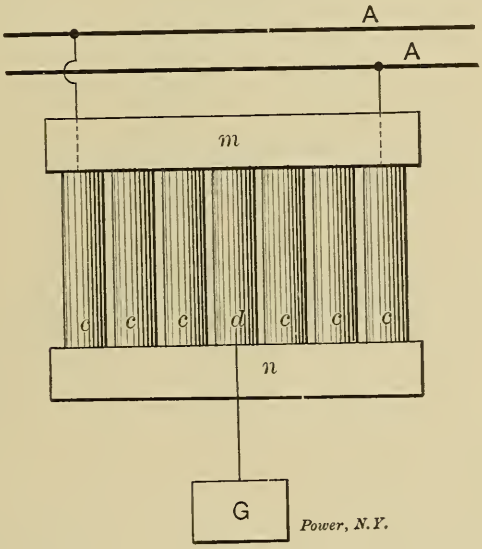

FIG. 136.

current cannot continue across the space. This operation is practically instantaneous, like blowing out a candle flame. The non-arcing arrester, Fig. 136, is simply a number of metal rods, *c* and *d*, mounted in blocks of insulating material, *m* and *n*, usually of porcelain. The end rods are connected to the two sides of the circuit and the central one to the ground. There are thus several air gaps in series between the middle rod and each end rod. The lightning jumps across readily, but the dynamo current does not continue after the lightning discharge. This arrester protects both sides of a circuit; the other types are single. It is used on alternating-current circuits only, but a non-arcing arrester for

direct-current circuits, which is equally simple, is shown by Fig. 137. This consists of a base-board of lignum vitæ, *B*, on which are mounted two metal blocks, *c*, *d*, constituting the terminals. Between the blocks are several very small grooves charred in the surface of the board; the carbonized grooves furnish a path for the lightning, carbon being a conductor, but their

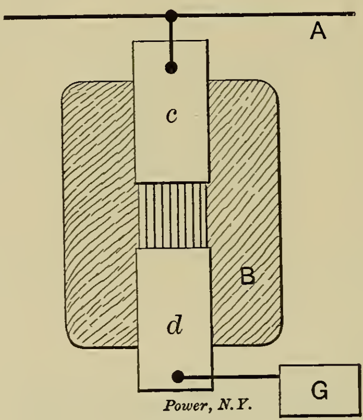

FIG. 137.

resistance is too high to carry the dynamo current. The dynamo current is prevented from following a lightning discharge by shutting in the grooves with another piece of lignum vitæ, the space then being so small that sufficient vapor to maintain an arc* cannot be contained.

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* The existence of an arc demands the presence of a vapor which reduces the resistance of the air gap. The vapor is created by the heat of the current volatilizing the material of the terminals between which the arc is established. In Fig. 134 carbon vapor is produced.

CHAPTER V.

MEASURING INSTRUMENTS AND MEASUREMENTS.

Q. 256—What is the principle of the voltmeter?

A.—Some voltmeters are based on the magnetic needle principle, as shown by Figs. 138 and 138A. A soft iron needle, *a,* is pivoted within a coil of very fine wire, *b,* and held normally out of line with the axis of the coil by means of a permanent magnet, *M,* or a weight, *w.* Passing a current through the coil, *b,* causes magnetic lines to flow (vertically in the illustrations) through

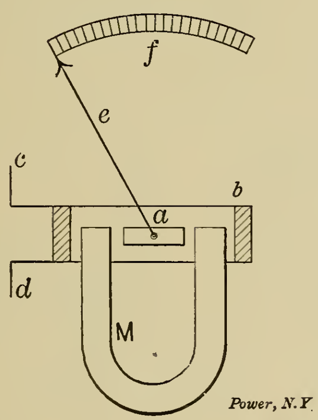


FIG. 138.

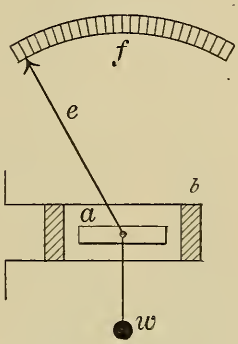


FIG. 138A.

its center (see answer to Q. 99) and these tend to pull the needle around into line with them. The permanent magnet, *M,* or the weight, *w,* resists this pull, and the distance that the needle is deflected indicates the strength of the current in the coil. A pointer, *e,* is attached to the needle, *a,* and the scale, *f,* is marked in volts; the pointer, *e,* indicates on the scale the E.M.F. at the terminals, *c, d,* of the coil, *b.* Fig. 139 shows the principle of a voltmeter in which a coil is pivoted between the poles of a magnet. Pass-

L. of C.

ing a current through the coil creates magnetic lines of force at an angle to those supplied by the permanent magnet. These lines tend to pull the coil around so as to put themselves parallel with the "field" lines of force. The coil is restrained by spiral springs,

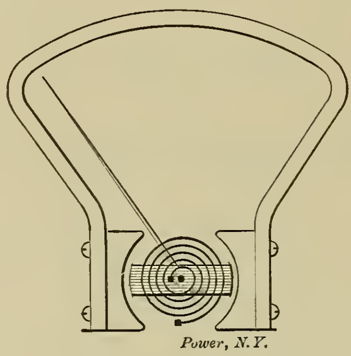


FIG. 139.

which also serve as connections for the winding; one spring is below the coil, and omitted from the sketch. The external appearance of Fig. 138 is shown by Fig. 140; that of Fig. 138A by Fig. 140A, and that of Fig. 139 by Fig. 141.

Q. 257—How does an ammeter work?

A.—Exactly like a voltmeter. When the coil is stationary, however, it is made of very heavy wire, because it is connected in

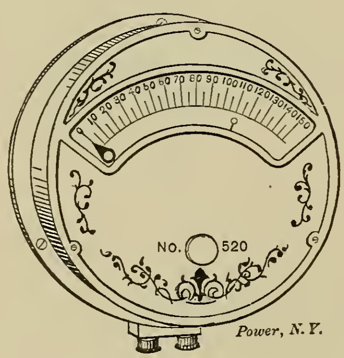


FIG. 140.

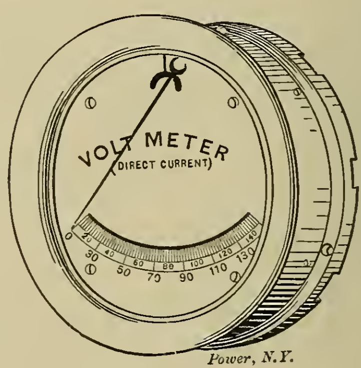


FIG. 140A.

series with the circuit and the full current goes through it. When the coil is pivoted it is made of fine wire, and a low-resistance shunt carries most of the current, but the dial is so graduated that the pointer indicates the whole current.

Q. 258—What other measuring instruments are generally used?

A.—Wattmeters and galvanometers. A wattmeter measures

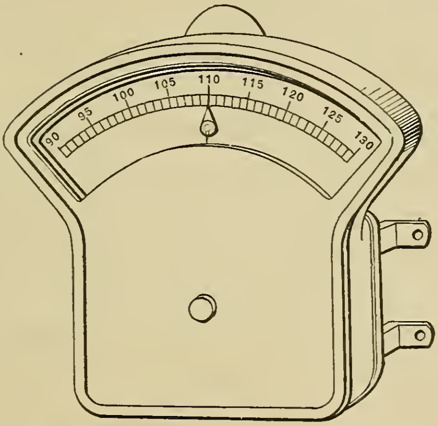


FIG. 141.

the power furnished to a circuit or device. It is usually made in the form of a very small motor which drives a delicate train of gears, the hands of which indicate on dials the number of watt-

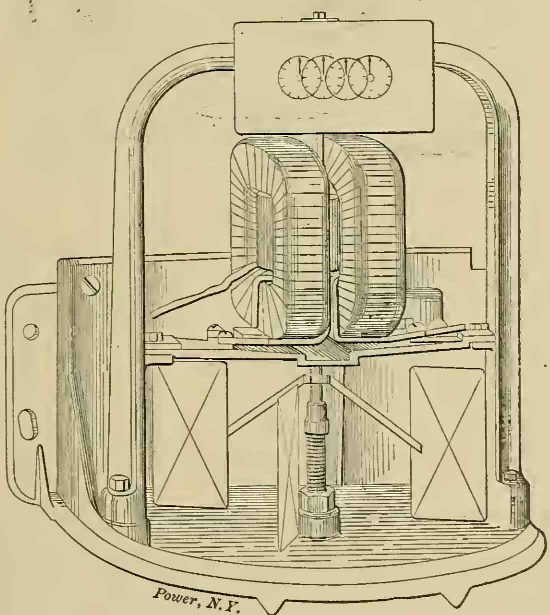


FIG. 142.

hours supplied. Such an instrument is really not a wattmeter but a watt-hour meter, because it registers the time as well as the power. Fig. 142 shows a widely used style of watt-hour

meter. The two coils of wire enclose the armature and furnish the field magnetism. The fan blades on the lower part of the shaft serve as a brake and steady the rotation of the shaft. There are several forms of motor-meters, all based on the same principle —that of making the speed of the motor proportional to the watts supplied to the circuit.

Q. 259—How do these meters measure the time of service?

A.—Simply by running when the current is passing and stopping when it stops. For example, if the motor shaft makes 10 revolutions a minute when 100 watts are being supplied, at the expiration of an hour it will make 600 revolutions. If 200 watts go through it will make 20 revolutions a minute, or 1200 an hour, so that 200 watts for half an hour, or 100 watts for an hour or 50

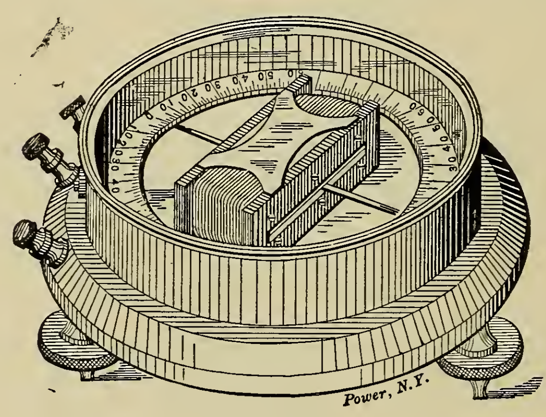


FIG. 143.

watts for two hours will each cause the motor to make 600 revolutions total, and the registration on the dials will be the same in all three cases. Watt-hour meters are made for both direct and alternating currents.

Q. 260—Why is the speed of the motor proportional to the watts supplied?

A.—Its field coils are in series with the circuit and no iron is used, so that the field strength varies exactly with the load. The armature is in shunt or parallel to the circuit, and its strength varies with the E.M.F. of the circuit. The product of the field and armature strengths, which varies with the product of the current and E.M.F., *i. e.*, the watts, determines the speed.

Q. 261—What is a galvanometer and what is it used for?

A.—A galvanometer is very much like the voltmeter in Fig.

140. It consists of a coil of fine wire in which is pivoted a hard steel bar magnet like a compass needle. (In a voltmeter the pivoted needle is of soft iron.) The galvanometer needle is in some cases held at zero by an outside magnet like the voltmeter needle, but in ordinary instruments it is simply allowed to point north and south like a compass needle, and the galvanometer is twisted around until the zero mark is under the pointer. The dial is graduated in degrees of the circle in some galvanometers; in others it is not graduated at all, but simply has a zero mark. Fig. 143 shows an ordinary galvanometer with a graduated dial. Galvanometers are used in testing for resistance, in an arrangement known as the Wheatstone bridge.

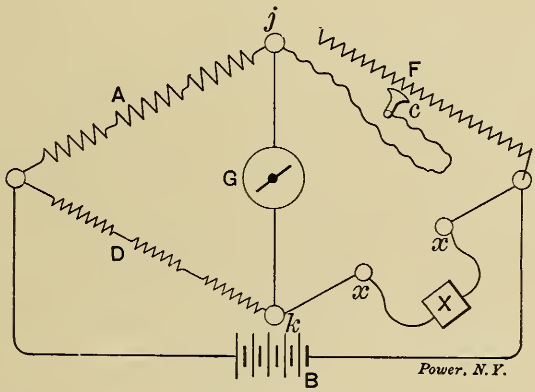


FIG. 144.

Q. 262—What is a Wheatstone bridge?

A.—A combination of resistance coils and a galvanometer, arranged as shown diagrammatically by Fig. 144. Here *A* and *D* are coils of known resistance, *B* is a battery, *G* a galvanometer, *F* a series of resistance coils which can be cut in or out by a movable contact, *c; x, x,* are binding posts to which the object to be tested is connected. Whenever the resistance of the test object (say a field magnet coil) *X,* bears the same relation to *F* that the resistance of *D* does to that of *A,* no current will pass through the galvanometer and its needle will remain at zero. Consequently, in using the apparatus the resistance, *F,* is adjusted until the galvanometer needle remains at zero, when the formula

$$\frac{DF}{A} = X \ldots\ldots\ldots\ldots\ldots\ldots (26)$$

gives the resistance of the test object. This formula is easily memorized by applying the "rule of three," thus

$$A : D :: F : X$$

In many cases the resistances, A and D, are made equal; then, of course, the resistance of F is the same as that of X when the galvanometer indicates zero.

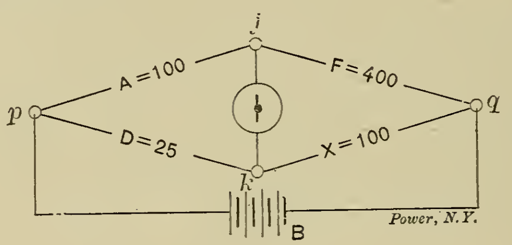


FIG. 145.

Q. 263—Why does the galvanometer indicate zero when $A : D :: F : X$?

A.—Because there is no difference of potential between j and k to force current across the galvanometer. This can be demonstrated by Ohm's law. Suppose the resistances have the values given in Fig. 145, and a current of 4 amperes flows through D and X and 1 ampere goes through A and F. The "drop" in D from p to k will be $25 \times 4 = 100$ volts and the "drop" in A will be $1 \times 100 = 100$ volts, leaving the potential at j and k exactly equal. When the "balance" between the two sides is disturbed,

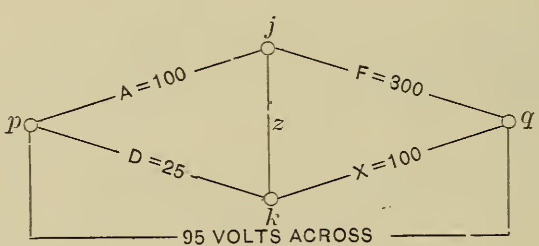


FIG. 146.

current will flow from one side to the other. Figs. 146, 147 and 148 illustrate this. In Fig. 146, a piece of wire, z, of negligible resistance is substituted for the galvanometer. This gives practically the electrical condition shown by Fig. 147. In these two diagrams the bridge is not balanced, A being four times D, while F is three times X. The result is most easily figured by con-

sidering the conductances* of the four legs. The resistance of *A* being 100 ohms, its conductance is $\frac{1}{100}$; *D* has a conductance of $\frac{1}{25}$. The conductance of the two, jointly, is $\frac{1}{100} + \frac{1}{25}$; or $\frac{1}{100} + \frac{4}{100}$, which is $\frac{5}{100}$. The *resistance*, therefore, of *A* and *D* combined, is $\frac{100}{5} = 20$ ohms Similiarly, *F* and *X* have a combined conductance of $\frac{1}{300} + \frac{1}{100}$ or $\frac{1}{300} + \frac{3}{300} = \frac{4}{300}$ or $\frac{1}{75}$; this means 75 ohms

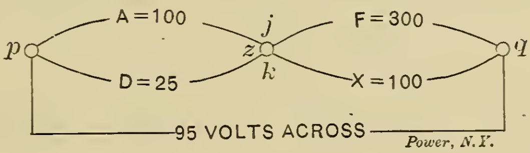


FIG. 147.

resistance The total resistance from *p* to *q*, therefore, is $20 + 75 = 95$ ohms, and the total current flowing will be 1 ampere. From *p* to *z* the current divides up into $\frac{1}{5}$ ampere in *A* and $\frac{4}{5}$ in *D*. from *z* to *q* it divides up into $\frac{1}{4}$ ampere in *F* and $\frac{3}{4}$ in *X*. Now in order to have $\frac{1}{5}$ ampere in *A* and $\frac{1}{4}$ in *F*, some current ($\frac{1}{20}$ ampere) must cross over from *D* to *F* through the joint, *Z*. If the galvanometer were inserted it would, of course, indicate the passage of this current and show that the bridge was " out of balance "

Fig. 148 shows the bridge in balance, the ratio *A*: *D* being the same as *F*: *X*. The conductance from *p* to *z* is $\frac{1}{75} + \frac{1}{18\frac{3}{4}}$ or $\frac{1}{75} + \frac{4}{75} = \frac{5}{75}$; hence the resistance is $\frac{75}{5}$ or 15 ohms. The conductance from *z* to *q* is $\frac{1}{100} + \frac{1}{400}$ or $\frac{4}{400} + \frac{1}{400} = \frac{5}{400}$, so that the resistance is $\frac{400}{5}$ or 80 ohms, making a total resistance from *p* to *q* of 95

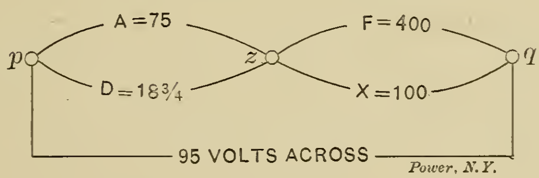


FIG. 148.

ohms, as before The total current will again be 1 ampere, but both *A* and *F* will carry $\frac{1}{5}$ ampere while $\frac{4}{5}$ flows through *D* and *X*, and no current will need to flow across at *z*.

---

* The conductance of a wire is equal to $\frac{1}{R}$, or 1 divided by the resistance. If a wire has a resistance of 100 ohms its conductance is $\frac{1}{100}$ The conductance of two or more wires connected in parallel is equal to the sum of their separate conductances, just as the resistances of several wires in series is the sum of their resistances. Inverting the conductance gives the resistance, and *vice versa*.

Q. 264—Why is it necessary to compute both resistance and conductance?

A.—One computes conductance when considering parallel circuits merely for convenience; having the conductance, it is changed into resistance, because the relation between *R, C* and *E,* given by Ohm's law, which is the foundation of all wiring calculations. The formula for the resistance of parallel circuits is

$$\frac{Ra \times Rb}{Ra + Rb} = R \text{ total}, \ldots\ldots\ldots\ldots (27)$$

for two branches, *Ra* and *Rb*. For three branches it is worse, namely,

$$\frac{Ra \times Rb \times Rc}{Ra \times Rb + Rb \times Rc + Rc \times Ra} = R \text{ total} \ldots (28)$$

It is evidently easier to compute

$$\frac{1}{Ra} + \frac{1}{Rb}, \text{ or } \frac{1}{Ra} + \frac{1}{Rb} + \frac{1}{Rc}$$

and invert the result.

Q. 265—Is the Wheatstone bridge used for testing dynamos?

A.—Sometimes, but it is more often used for testing objects of high resistance, such as small magnet coils and the insulation of circuit wiring.

Q. 266—How is insulation tested?

A.—One way is to connect one of the x terminals of the bridge to one bus-bar, and the other x terminal to the other bus-bar; turn all the lamps off at the sockets, but leave all circuit switches closed except the dynamo switches. The bridge then shows the resistance between the two sides of the circuit, and the amount of leakage (usually too small to consider) may be ascertained. This applies only to constant-potential or parallel circuits.

Q. 267—Why is the bridge not generally used for testing dynamos?

A.—Because the galvanometer is extremely sensitive and liable to disturbance from outside sources, such as heavy pieces of iron, dynamo magnets, etc. This trouble is sometimes evaded by using a telephone receiver instead of a galvanometer. The receiver is held to the ear and connected and disconnected by means of a contact key. As long as a clicking sound is distinguishable in the telephone when the key is opened and closed the bridge is out of

balance; when no click can be heard, it is balanced, and the calculation $\frac{D \times F}{A} = X$ may be made.

Q. 268—Are there any other methods of measuring resistance?

A.—Yes. One of the most convenient to use around power stations is the ammeter and voltmeter method. This is represented by Fig. 149, in which *x* and *x* are the posts to which the test object is connected, and *B, B* are posts to be connected with a source of current, such as an incandescent circuit. The rheostat should be

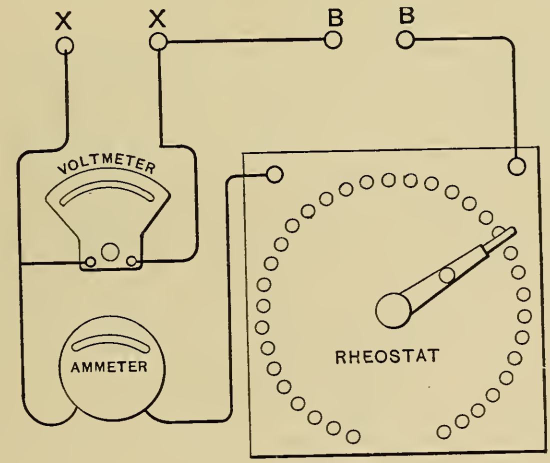


FIG. 149.

capable of carrying 10 amperes continuously, and should have a total resistance of 100 to 125 ohms. The test is made by adjusting the rheostat until the ammeter indicates one ampere (if the test object can stand it), when the voltmeter will indicate directly the resistance in ohms of the object. If the latter is a heavy wire coil the rheostat may be adjusted until 10 amperes flow; then the resistance will be $\frac{1}{10}$ of the voltmeter reading. When $\frac{1}{10}$ ampere flows the resistance is ten times the voltmeter reading. The current supplied at the binding posts, *B, B*, must be "direct," not alternating.

CHAPTER VI.

ALTERNATING CURRENTS.

Q. 269—What is alternating current?

A.—A current, the polarity of which constantly changes from positive to negative and back again, *i. e.*, which flows first in one direction, and so on. Referring again to Figs. 74 and 75, on page 54, it will be seen that in order to maintain a continuous flow of current in the circuit *W* it was necessary to introduce the commutator. Omit the commutator and make the connections

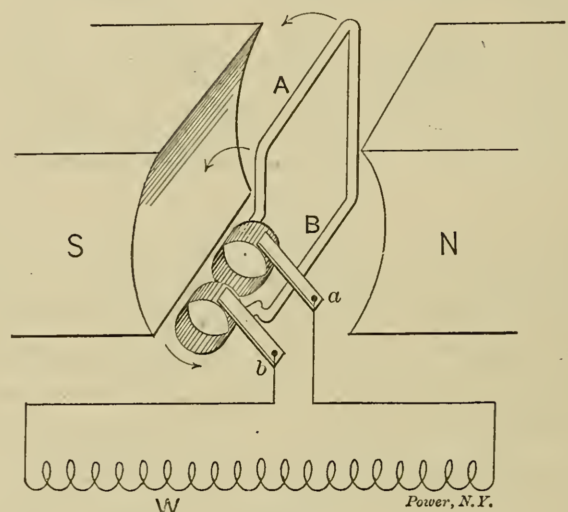


FIG. 150.

from coil to circuit permanent by sliding contacts, as in Fig. 150, and the current in *W* will be alternating. When *A* passes the *S* pole the current will flow from left to right in the outside circuit; when *A* passes the *N* pole the direction of the current is reversed throughout the whole circuit, flowing from right to left in *W*.

Q. 270—What are the rings called that the brushes bear upon.

A.—Collector rings. No matter how many armature coils a simple alternator has, there are only two collector rings.

Q. 271—Does the current change from positive to negative suddenly?

A.—No; it rises from nothing or zero to maximum in one direction (say positive), and then goes back to zero and rises to maximum in the opposite direction; then it falls to zero and reverses again, and so on. When the loop or coil is midway between poles, as in Fig. 150, the E.M.F. is zero, and it rises gradually as the wire approaches the pole-piece, *S*, reaching maximum as the wire passes the center of the pole-piece, and then beginning to die away.

Q. 272—Can the variation in E.M.F. be shown by a diagram, as an indicator diagram shows the change in steam pressure?

A.—Yes. Fig. 151 is such a diagram. If a drum like an indi-

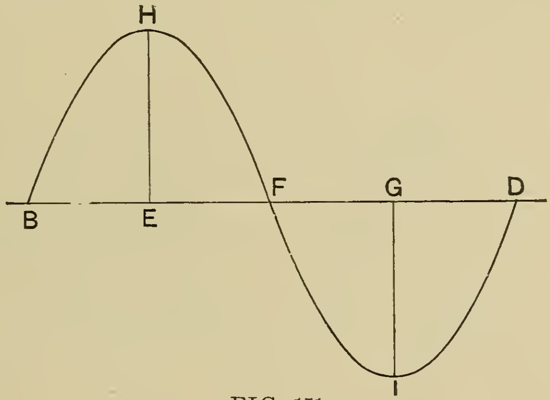


FIG. 151.

cator drum were revolved steadily and a pencil could be so arranged as to rise above a central zero line as the E.M.F. rises in the positive direction and be drawn below the line as the E.M.F. rises in the negative direction, it would trace such a curve on the paper of the drum.

Q. 273—How does Fig. 151 apply to Fig. 150?

A.—Comparison of Figs. 151 and 152 will show this. Fig. 152 represents the four extreme positions occupied by any one wire of a coil during one complete pair of reversals. The E.M.F. at each point is shown by Fig. 151, the reference letters under the drawings of Fig. 152 corresponding with those on the diagram. The vertical dotted lines in Fig. 152 represent the passage of magnetic flux from pole to pole.

Q. 274—Then the vertical distance from the zero line to a point on the curve in Fig. 151 shows the E.M.F. at the point?

A.—Exactly. The curve here shown is drawn to the scale of 2,000 volts per inch. Hence the E.M.F. at *H* and *I* is 1,414.2 volts, represented by the length of the lines *EH* and *GI*.

Q. 275—Why is no E.M.F. generated when the wire is midway between the poles? It is moving in magnetic lines.

A.—Yes; but not cutting across them. The wire moves parallel with the lines for a short distance before it begins to cut across them, and parallel motion does not generate any E.M.F.

Q. 276—When the E.M.F. is always fluctuating, how can it be measured, and what is taken as the working E.M.F.?

A.—The geometrical average is taken as the working E.M.F. This is called the effective electromotive force. It is measured by voltmeters designed especially for alternating current. The

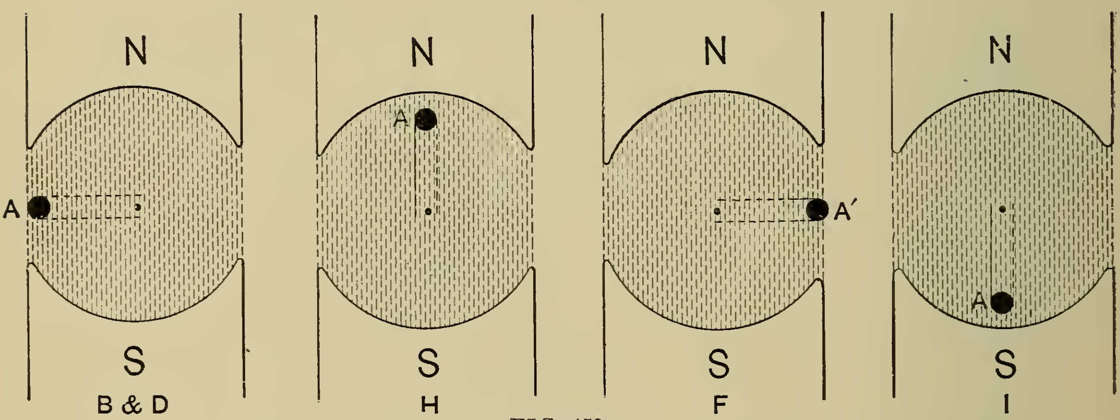


FIG. 152.

voltmeter can not respond to the enormously rapid fluctuations of the alternating current, but indicates the effective E.M.F.

Q. 277—Is the effective E.M.F. one-half of the maximum?

A.—No; it is 0.707 of the maximum. Or, to express it the other way, the maximum is 1.414 times the effective E.M.F. Thus, the effective E.M.F. of the curve Fig. 151 is 1,000 volts. The accurate relation between the two is

$$\frac{E_{\text{max}}}{\sqrt{2}} = E; \text{ or } E \times \sqrt{2} = E_{\text{max}}.$$

The square root of 2 is 1.4142136 +, but in practical working 1.414 is considered sufficiently accurate; in fact 1.4 is frequently used as the ratio of E_{max} to E.

Q. 278—Is the effective E.M.F., *E*, of alternating current the same as the E.M.F., *E*, of continuous current?

A.—Yes, practically. It is assumed to give the same results, excepting the strain on insulation. When this is considered E_{max} is always used.

Q. 279—Then the E.M.F. tending to pass through the insulation of a 1000-volt alternating-current dynamo is 1414 volts?

A —Of course; because the full E.M.F. exists periodically for a brief instant. In reckoning the circuit E.M.F. the effective pressure is considered, and whenever the terms voltage, potential, E.M.F. and pressure are used in dealing with alternating currents the effective E.M.F. is meant, unless the maximum or some other value is actually specified.

Q. 280—Does the E.M.F. always rise and fall twice in a revolution as indicated by Figs. 151 and 152?

A.—In a bipolar machine it would, because it rises and falls once every time a coil passes one magnet pole, or twice for each pair of poles. Alternators are always multipolar, however, so that the number of complete curves like Fig. 151, or "cycles," that are described in one revolution of the armature depends upon the number of poles. The number of cycles per revolution is one-half the number of poles,

Q. 281—What is meant by cycles?

A.—One rise E.M.F. in the positive direction and one in the negative direction, ending at zero, is a cycle. The number of cycles per second is called the "frequency." A physical conception of an electrical cycle may be formed by remembering that one cycle of any series of repeated operations extends from the beginning of one operation to the point where that same operation starts to repeat. For example, if one were engaged in a series of operations which were periodically repeated, such as carrying an armful of material from *A* to *B*, depositing it, going back to *A* empty handed, securing another armful, carrying it to *B*, and so on over and over, each complete set of operations up to the point where repetition begins, would be one cycle or "period," as it is also called. Hence, the passage of any one wire or coil or set of coils on an alternator armature from any given position with relation to the field magnet to the next identical position constitutes one cycle or period. For example, if a coil passes from a point opposite to the center of a north pole to a point opposite the center of a south pole, it will not have passed through a cycle be-

cause the two poles are different. But when it reaches the center of the next pole the cycle is complete.

Q. 282—Then a cycle extends from the center of one magnet pole to the center of the next magnet pole of the same polarity?

A.—A cycle doesn't "extend" in that sense. A wire traversing that distance passes through one cycle of generation. The cycle may be taken as starting at any point—not necessarily when a coil is under the center of a pole. The cycle generally considered is the one beginning when a coil is generating no E.M.F., as in the first and third positions shown by Fig. 152. The end of any cycle or period is reached when the coil or wire under consideration begins to do again precisely what it was doing at the beginning of the cycle or period.

CHAPTER VII.

ALTERNATING CURRENT GENERATORS.

Q. 283—Why are alternators always multipolar?

A.—Because it is desirable for the frequency to be high—from 30 to 140 cycles per second—and this would require too many revolutions of the armature for mechanical safety. For example, at 30 cycles, the lowest frequency generally used, the armature of a bipolar machine would have to make 30 revolutions a second,

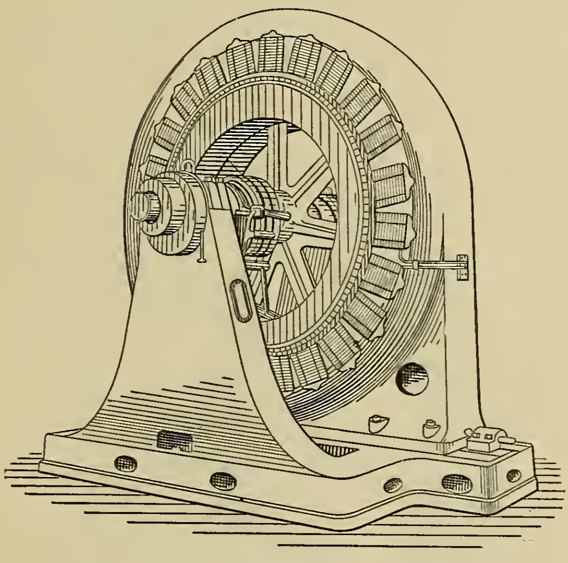


FIG. 153.

or 1800 a minute, which is impracticable for machines of considerable output.

Q. 284—Are there different types of alternators?

A.—Yes; there are three general types. The one most used consists of an ordinary multipolar field with a revolving armature, as indicated by Fig. 153. A similar type has a stationary armature and a revolving field magnet.

Q. 285—How is the field magnet arranged to revolve?
A.—It is mounted inside the armature, which is a ring of large

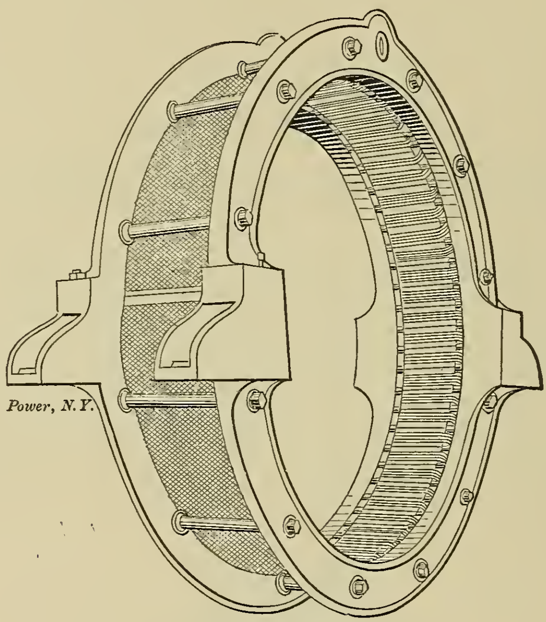


FIG. 154.

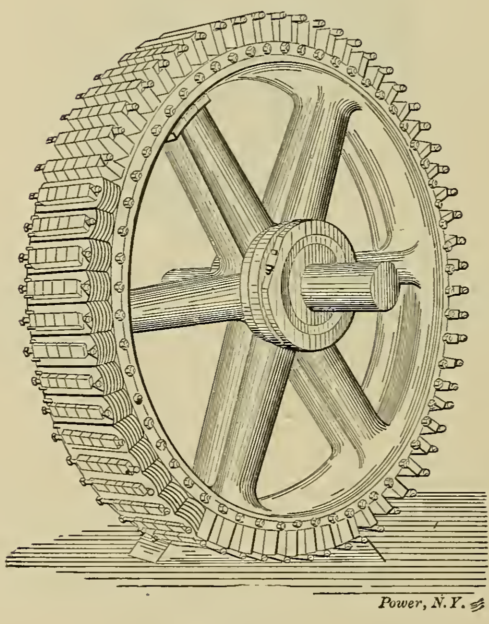


FIG. 155.

diameter, as shown by Fig. 154. The field magnet is a wheel with poles projecting externally, as in Fig. 155, instead of internally.

Q. 286—What are the advantages of such a type?

A.—The generation of higher potentials, made practical by reason of the fact that the armature wires can be more securely fastened and more effectually insulated. The collector rings and brushes are only two in number and carry small currents at low potentials, making them safe to handle. The armature terminals being stationary, they can be enclosed permanently so that no one can come in contact with them, and they can, therefore, have a potential much higher than would be safe for collector rings and brushes.

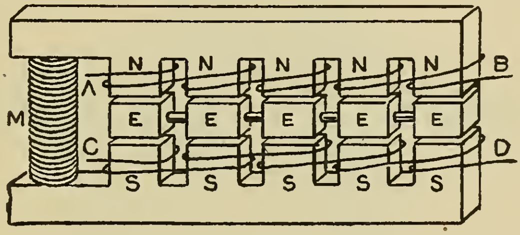


FIG. 156.

Q. 287—What other type of alternator is there?

A.—The inductor type, in which all of the wires are stationary. The principle is illustrated in Figs. 156 and 157, where a magnet *M*, is shown provided with extended poles, each divided into five small pole-pieces, the two rows facing each other, and wound with coils *A*, *B*, and *C*, *D*. Between the opposing rows of pole-pieces are as many iron blocks, *E*, as there are poles on each side. Now imagine the magnet *M* excited; then one row of poles will be north and the other south, as indicated, and lines of force will flow across from the *N* poles to the *S* poles through the blocks *E* when they are in the position shown by Fig. 156. Now pull the blocks sidewise to the position in Fig. 157, and the number of magnetic lines

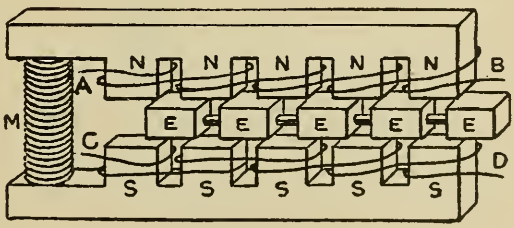


FIG. 157.

of force passing across through the coils is greatly decreased by reason of the higher reluctance* of their path. This decrease induces an E.M.F. in the coils *A*, *B*, and *C*, *D*, and if there were an endless string of blocks, *E*. and they were kept sliding, an impulse

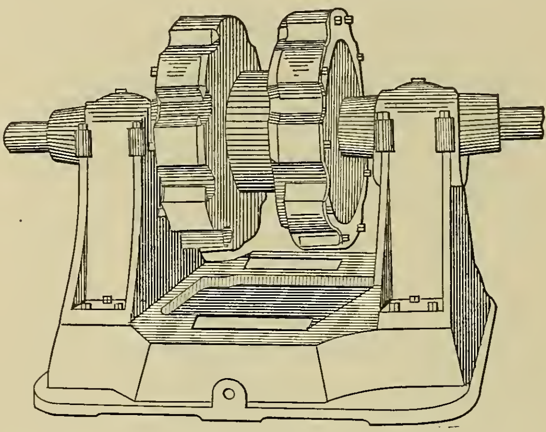


FIG. 158.

of E.M.F. would be induced in one direction every time the magnetism was increased by the relation shown in Fig. 156 and an impulse in the opposite direction would be induced every time

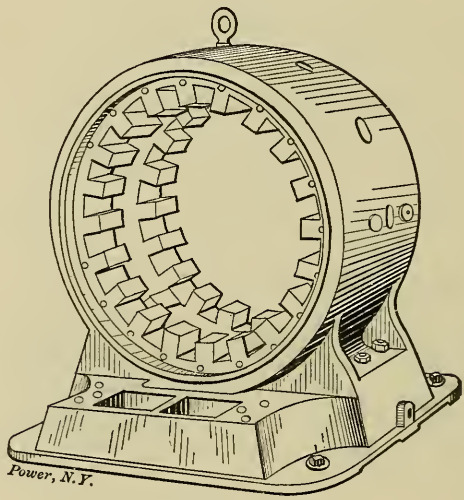


FIG. 159.

the position in Fig. 157 was occupied by the slider. Thus a regularly alternating current would flow in the coils if their ends were connected to a closed circuit.

* Reluctance is magnetic resistance.

Q. 288—How is this condition attained in an actual machine?

A.—The blocks, *E*, are arranged on a drum, as in Fig. 158, and the pole-pieces on the interior of a shell, as in Fig. 159, and the drum is revolved within the shell so that the projections pass con-

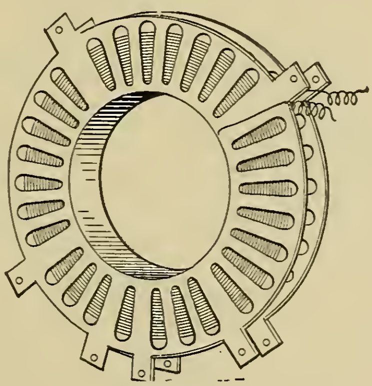


FIG. 160.

tinuously before the pole-faces. The two rows of poles are side by side instead of facing each other, and there are two corresponding rows of projections on the revolving drum. The pole-pieces are magnetized by a single coil (Fig. 160) which fits in be-

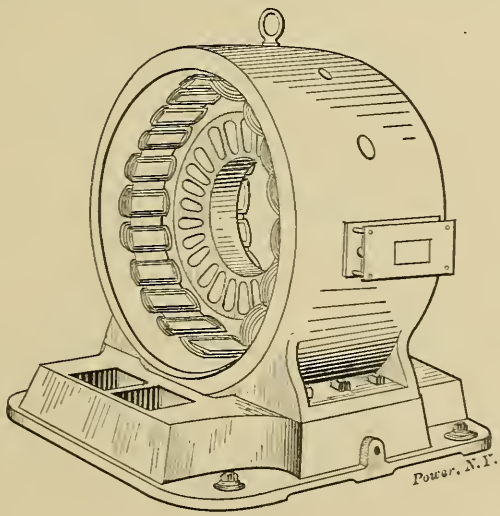


FIG. 161.

tween them. Fig. 161 shows the shell with all the coils and Fig. 162 the complete machine.

Q. 289—In this type of machine are the coils wound on the pole-pieces the armature coils?

A.—Yes; as the functions of the field and armature are so mixed up, however, the usual terms are not applied to an inductor

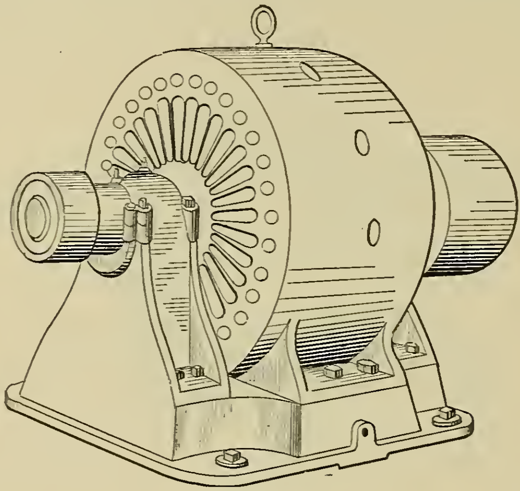


FIG. 162.

alternator. The stationary shell and poles as a whole are called the "stator;" the revolving part is the "rotor," and is also called the "inductor" (an inappropriate and inexact name); the big single coil is called the field coil or the "exciting" coil; the smaller

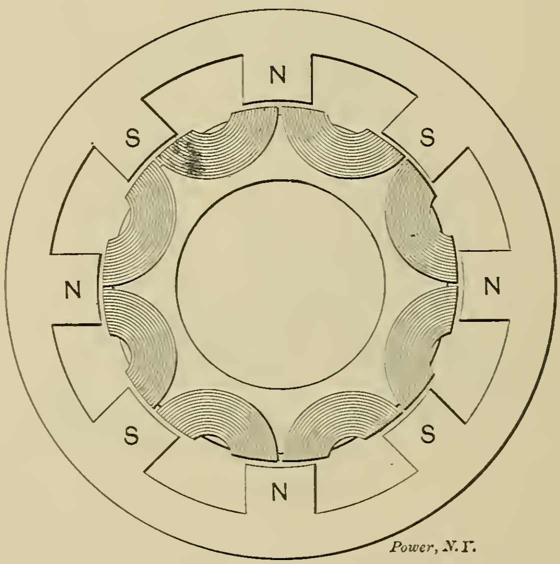


FIG. 163.

coils are variously known as "induction" coils, "service" coils and armature coils. The last term is highly inappropriate and

only used because these coils perform the same work that armature coils do in a conventional type of dynamo.

Q. 290—Is the armature of an ordinary alternator wound like that of a continuous current dynamo?

A.—Not usually. In a simple alternator there are generally as many coils as magnet poles. A coil may have many turns of wire, but the number of coils is governed by the number of poles.

Q. 291—Why?

A.—Because the E.M.F. must rise and fall at practically the same instants in every wire on the armature in order that the individual E.M.F's of the wires may add up to the greatest total.

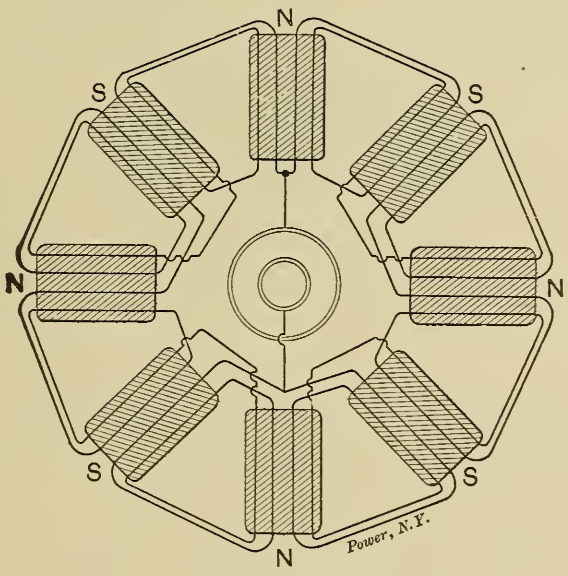


FIG. 164.

Fig. 163 shows an eight-pole alternator with eight armature coils, in outline. It will be noticed that every coil occupies exactly the same relative position with regard to the field, so that when the E.M.F. rises in one coil it rises in all of them.

Q. 292—Are the coils laid on the surface of the core, or in slots?

A.—Armatures are built both ways, but the slotted core is mostly used.

Q. 293—How are the coils connected?

A.—All in series usually. Sometimes they are connected in two parallel groups, in which case the E.M.F. is one half as great

as when all are in series. Fig. 164 is a diagram of the series arrangement and Fig. 165 is a diagram of the other. As it is not practicable to show a complete cylindrical surface in a diagram the coils are drawn as though the armature were a flat disk and

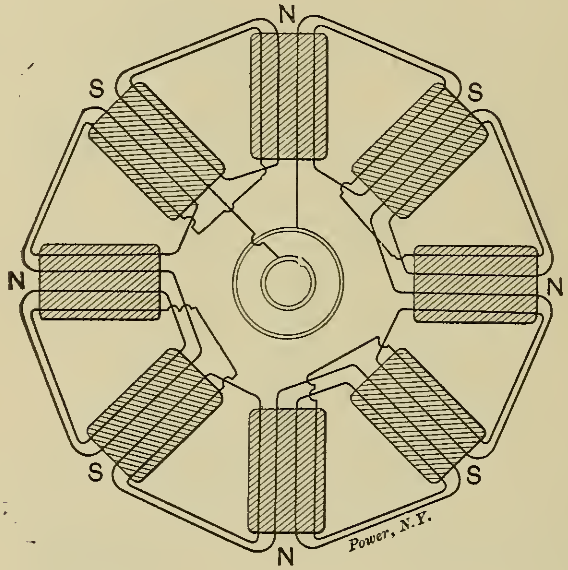


FIG. 165.

they were laid against one face of it. The poles are shown as though pointing parallel with the shaft, to correspond with the coil position.

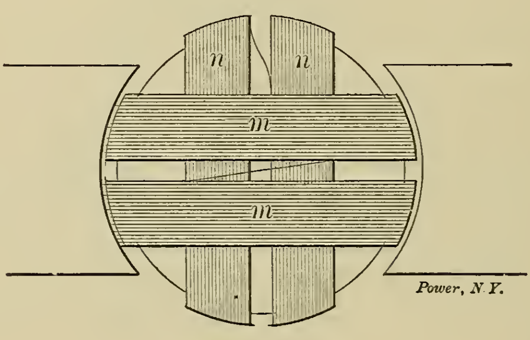


FIG. 166.

Q. 294—What would happen if another set of coils were put in the blank spaces on an alternator armature core?

A.—Each set would generate an E.M.F., but the E.M.F. of one would be maximum when that of the other was zero. Fig. 166

shows why. The coils, *m*, *m*, are cutting magnetic lines at the maximum rate, while *n*, and *n*, are cutting none. The effect is the same, of course, in a multipolar machine like Fig. 167, where all

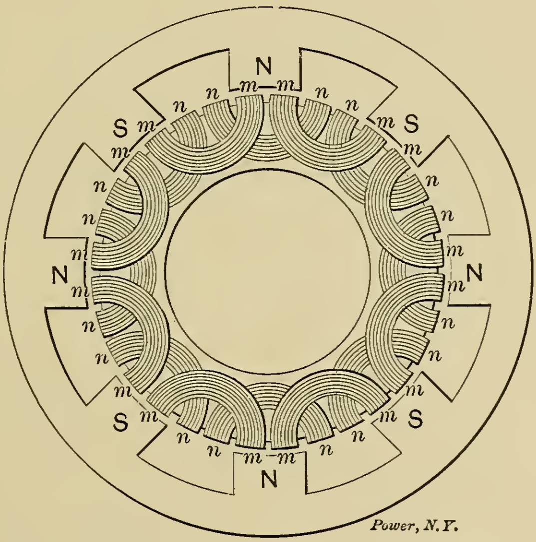


FIG. 167.

of the coils shown as cutting lines of force are marked *m*, and the others *n*.

Q. 295—Could not a machine be used with such a winding?

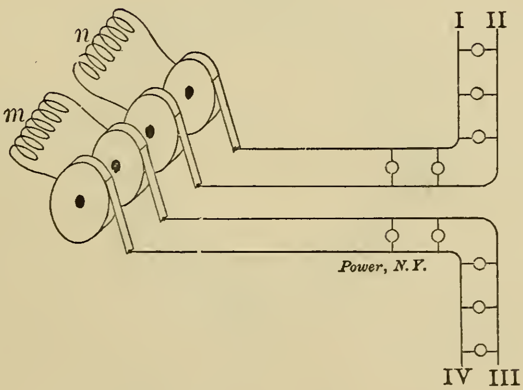


FIG. 168.

A.—Yes; many such are in use. But the two sets of coils are connected up separately, with separate pairs of collector rings, and usually supply two separate circuits, as shown by Fig. 168.

Q. 296—What is such a machine called?

A.—A two-phase alternator. Two-phase means that the armature generates two distinct E.M.Fs. differing in phase.

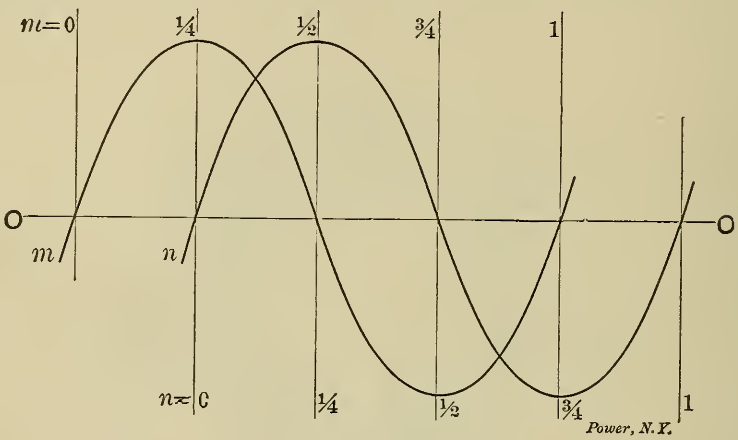


FIG. 169.

Q. 297—What does differing in phase mean?

A.—That the two E.M.Fs. rise and fall at different instants. Fig. 169 shows the E.M.F. curves of the two sets of armature coils.

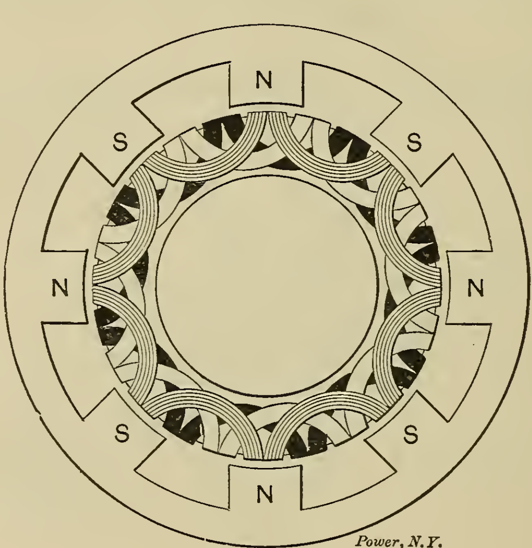


FIG. 170.

Q. 298—What do the figures indicate?

A.—Fractions of a cycle. Thus, when the coils, *m,* have passed through ¼ of a cycle, the coils, *n,* are just beginning one, and so

on, the n coils being always one quarter of a cycle behind the m coils.

Q. 299—Are more than two sets of coils ever used?

A.—Yes; alternators are built to give three phases, in which case three sets of armature coils are used.

Q. 300—How are they arranged?

A.—Generally as shown in Fig. 170. Each set occupies one-third of the available space around the circumference of the armature, and the three sets reach their maximum E. M. F's at equal intervals, one-third of a cycle apart, as shown by the three curves, Fig. 171, which shows two cycles. In Fig. 170 the different sets of coils are distinguished by making one set white, one black and

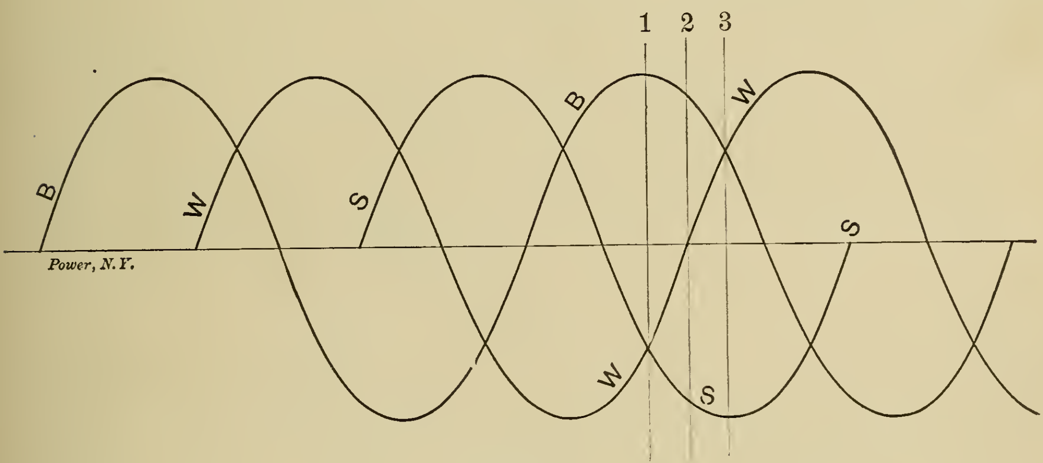


FIG. 171.

one shaded. In Fig. 171 the curves of the three sets are identified by the letters *W* (white), *B* (black) and *S* (shaded).

Q. 301—Has each set a separate pair of collector rings, like a two-phase armature?

A.—No. There are only three collector rings usually; four can be used, but the fourth is not generally employed. Fig. 172 is a diagram of the armature connections; the letters, *B*, *W* and *S* indicate the black, white and shaded coils of Fig. 170.

Q. 302—Are the three rings arranged in a triangle, as drawn?

A.—No; they are on the armature shaft side by side.

Q. 303—If all three coils are connected in series, as in Fig. 172, why does not the current simply pass around through them?

A.—Because the E.M.F's of the coils are out of phase; *i. e.*,

they rise to maximum at different instants, and the sum of the three at any instant equals zero. So, if the circuit wires were disconnected no current could flow in the three armature windings.

Q. 304—How can the sum of three E.M.Fs. be zero?

A.—Because two of them always oppose the other one, except when one is at zero; then the other two oppose and neutralize each other. Reference to the curves of Fig. 171 will show that whenever the E.M.F. of one coil is maximum in one direction the added E.M.F's of the other two are equal to it, but in the opposite direction. For example, at *1* the E.M.F. of *B* is 1,400, say,

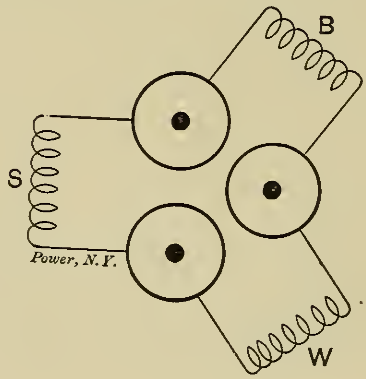


FIG. 172.

in the positive direction, while the E.M.F. of *W* and that of *S* are each 700 negative, or 1,400 negative combined. Thus, they equalize the E.M.F. of *B*. At 2, the E.M.F. of *B* is 1,212 volts positive, while that of *S* is 1,212 volts negative and *W* is zero—a condition of perfect balance. At *3*, the E.M.F. of *S* is at negative maximum while *B* and *W* are each 700, or one-half maximum, in the opposite direction, maintaining the equilibrium of the three E.M.F's. This condition of equilibrium exists at every instant during a cycle.

CHAPTER VIII.

ALTERNATING CURRENT CIRCUITS—ALTERNATOR FIELD EXCITATION.

Q. 305—How are the circuits of three-phase machines arranged?

A.—As in Fig. 173. The receiving devices are connected across each pair of wires.

Q. 306—Is not Fig. 173 the same as the three-wire system of direct-current work?

A.—Not at all. The E.M.F. between I and II is that due to the coils *W*. Say this is 1,000 volts, effective. Then the E.M.F. from II to III supplied by the coils *B* is also 1,000 volts, and similarly the E.M.F. between I and III is 1,000 volts, because it is supplied by the coils *S*, and each set of coils gives the same E.M.F.

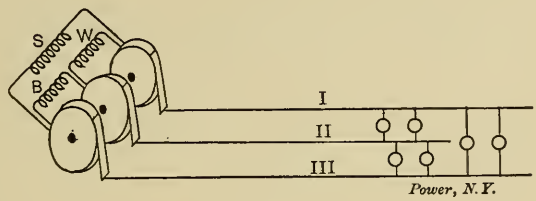


FIG. 173.

Q. 307—But why is not the E.M.F. of the coils *B* added to that of the coils *W?*

A.—It is, but the E.M.Fs. are out of phase, as before described, to such an extent that the sum of the E.M.F's generated by two sets of coils never exceeds the maximum of one of them. Fig. 174 is a diagram showing the relation of the three E.M.F's to the circuits, at the instants *1*, *2* and *3*, in Fig. 171. It is plain that the sum of, or the difference between, the E M F's from I to II, and

from II to III, always equals and opposes the E.M.F. direct from I to III.

Q. 308—How are the connections arranged for four collector rings on a three-phase alternator?

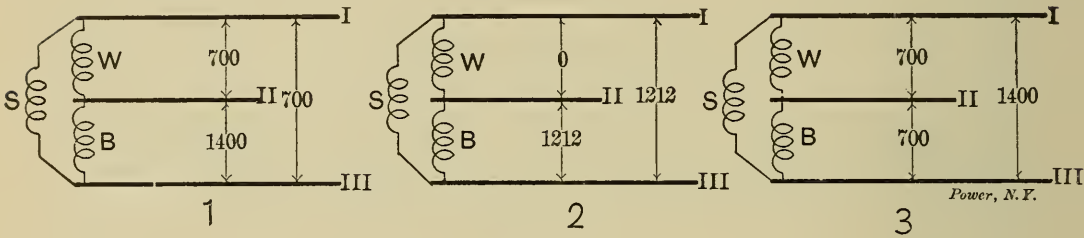


FIG. 174.

A.—As in Fig. 175. Here the coils are not connected in a continuous closed circuit, as in Figs. 172 and 173, but one end of each coil is connected to a common ring, and the other ends to individual rings. Four line wires are used, as shown. The E.M.F. between I and II is the sum of (or difference between) those of *S* and *W*; between II and III, the combined E.M.F's of *W* and *B*, and bewteen III and I it is the combined E.M.F's of *B* and *S*. Between IV and any other wire the E.M.F. is simply that due to the one set of coils in circuit there.

Q. 309—Does this arrangement balance like Figs. 172, 173 and 174?

A.—Yes; but there is a difference in line pressures. With the same alternator and other conditions, the effective E.M.F. be-

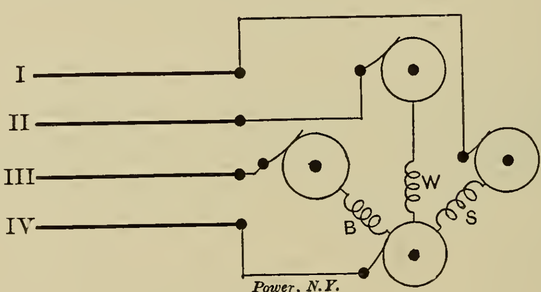


FIG. 175.

tween any two of the three principal wires, I, II, III, is 1.732 times the E.M.F. in the arrangement shown by Figs. 172 to 174, because two sets of coils are in series between each pair of wires.

Q. 310—What is the fourth wire for?

A.—To secure greater independence between the three legs of the system. Fig. 176 shows the elementary plan of this type of distribution. In practice, however, the fourth wire and collector

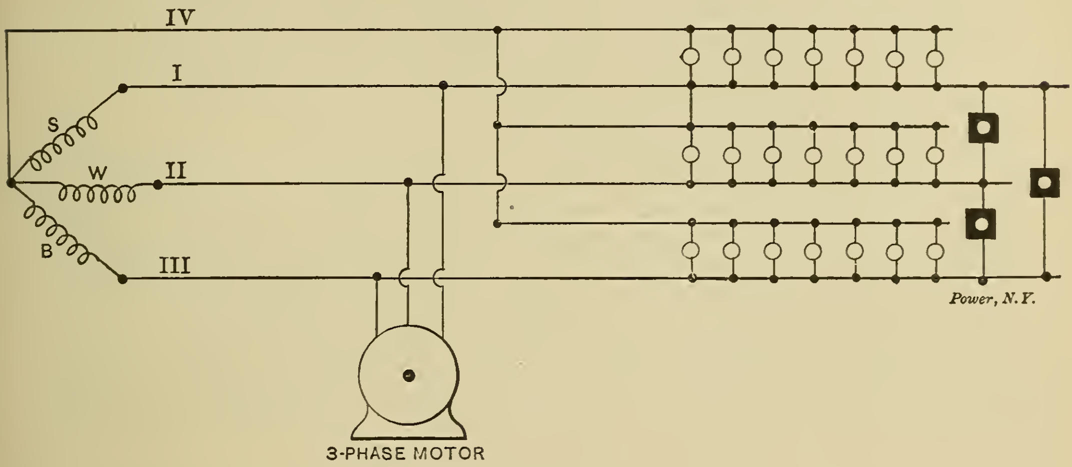


FIG. 176.

ring are not often used, and the circuit connections are as in Fig. 177.

Q. 311—Are there any distinguishing names for the two arrangements of three-phase armature windings?

A.—Yes. The armature arrangement in Figs. 172, 173 and 174 is called the "delta" connection, and that in Figs. 175 and 177 is the "star" or "Y" connection.

Q. 312—Do the E.M.F's of a two-phase system balance like those just described?

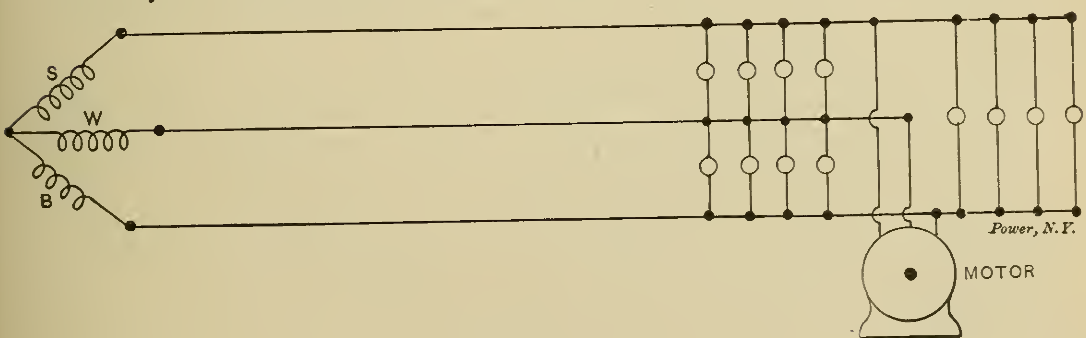


FIG. 177.

A.—No; it is not necessary, because the two circuits are usually kept entirely distinct, as in Fig. 168. Sometimes the two middle wires are consolidated into one, as in Fig. 178. Even then a zero

balance between the E.M.F's is not essential, nor could it be obtained with the ordinary arrangement of armature windings.

Q. 313—Is not this like the three-wire direct-current system?

A.—Precisely, except as to the amount of saving and ease of regulation. The windings *m* and *n* may be considered as separate armatures working in one field, instead of in separate fields as in the continuous-current system. But, as the E.M.F's are out of phase, the total E.M.F. from I to III is not twice that from I to II, but 1.414 times that value. Thus, if the E.M.F's from I to II and from II to III are each 100 volts, the E.M.F. measured direct from I to III will be 141.4 volts. This would not maintain the load if II were removed; hence, even with a perfectly divided load there is current in II. In fact, the current in II will be 1.414 times that in I or III if the system is perfectly balanced, because it is the

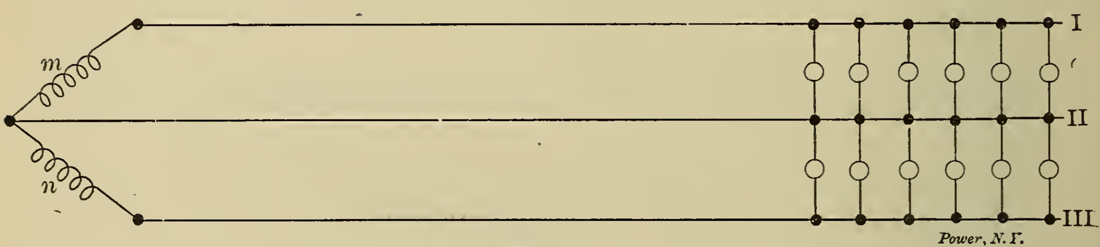


FIG. 178.

combination of two equal currents a quarter of a cycle apart in phase. Therefore, the middle wire must be about 1½ times the area of each outer wire.

Q. 314—Then alternating currents differing in phase combine just as the E.M.F's do?

A.—Exactly. Two equal E.M.F's a quarter-cycle (commonly designated 90 degrees) apart as to phase, if combined in series give a resultant E.M.F. 1.414 times the value of each original E.M.F. The same is true of equal currents a quarter-cycle apart in phase, combined in parallel.

Q. 315—What is the result when the difference of phase is something else than a quarter-cycle?

A.—The greater the difference in phase the less will be the resultant E.M.F. Resultant E.M.F's or currents can be plotted by the parallelogram of forces if we resort to the fiction of angular displacement to represent the difference in phase. For example,

suppose the E.M.F. or current to be supplied by a bipolar generator (which is never done). Then draw the circle through which any given armature wire passes in one revolution, and let the radius of the circle represent the maximum E.M.F. (or maxi-

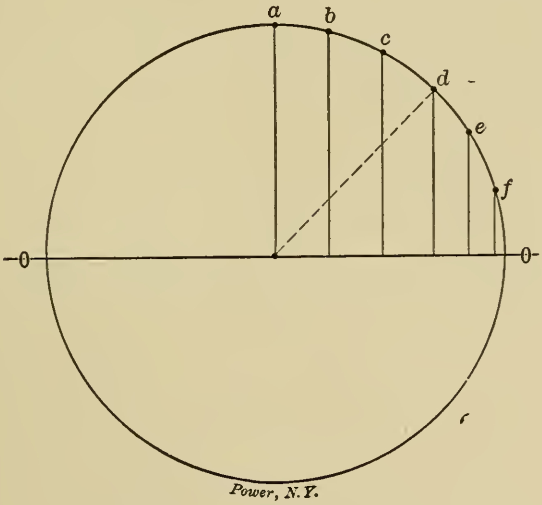


FIG. 179.

mum current) generated by those armature coils which are connected in series. Thus, if the maximum E.M.F. is 1,000 volts, and we let each $\frac{1}{8}$ inch of radius represent 100 volts, the circle will have a radius of $1\frac{1}{4}$ inches. Now draw a horizontal line through the center, as in Fig. 179, and call that the zero line. Then a perpendicular line from this to any point on the circumference of the circle will represent the E. M. F. when the central wire of the armature coil is at a part of its travel corresponding with this point. Compare Figs. 179 and 180. The E.M.F. generated by the winding when its center is in each position shown

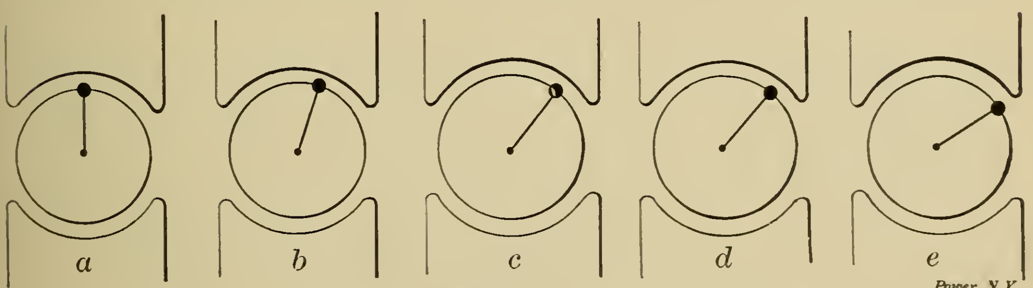


FIG. 180.

by the dot, Fig. 180, is indicated by the corresponding perpendicular lines in Fig. 179. This demonstration can be carried around the whole circle, of course. Here a cycle corresponds literally with a circle; a quarter-cycle is, therefore, 90 degrees of a circle; a sixth of a cycle is 60 degrees of a circle, and so on. And a cycle is always considered as equal to a circle, and parts of a cycle are represented by degrees of a circle, no matter how many magnet poles there are.

Q. 316—Then a difference of phase of an eighth of a cycle would always be equal to 45 degrees of a circle?

A.—Exactly. It is not necessary to draw the circle, only the radius lines being required to compare E.M.F's differing in phase.

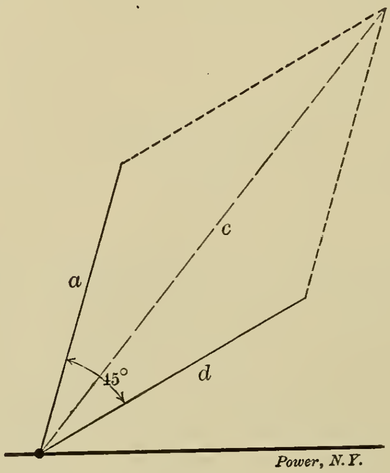


FIG. 181.

For example, if we have two E.M.F's of 100 volts each, differing in phase by $\frac{1}{8}$ cycle or 45 degrees, we simply draw two lines, *a* and *d,* Fig. 181, radiating 45 degrees apart from a common center. The length of each line represents the E.M.F.; thus, the lines are $1\frac{1}{4}$ inches long, which means that each $\frac{1}{8}$ of an inch represents 10 volts. Now construct the parallelogram exactly as in mechanical work and draw the diagonal, *C*. Then every eighth of an inch of *C* will mean 10 volts resultant E.M.F. In the diagram *C* is $2\frac{5}{64}$ inches long, which, at the scale of *a* and *d* (10 volts per $\frac{1}{8}$ inch), means a resultant E.M.F. of 185 volts.

Q. 317—Suppose the E.M.F's are not equal?

A.—Then make the lengths of *a* and *d* differ as the E.M.F's

differ in value; construct the parallelogram, and its diagonal will give the value of the resultant E.M.F.

Q. 318—Does this refer to effective or maximum E.M.F.?

A.—Either. If *a* and *d* are drawn to scale with the effective values, which is customary, then *C* gives the resulting effective value. If you start with the maximum values the resultant will be the maximum, and must be divided by 1.414 or multiplied by 0.7071 to reduce it to the effective E.M.F. or current, as the case may be.

Q. 319—Is the current spoken of as effective and maximum also?

A.—Yes. It fluctuates exactly like the E.M.F. does, of course, and the current values in amperes are treated exactly like the E.M.F. values in volts.

Q. 320—Cannot the combined E.M.F's. be found without drawing diagrams?

A.—Yes. If two E.M.F's of different phase, but equal values, be combined the resultant E.M.F. will be $E_r = (E_a + E_b) \times \cos(\frac{1}{2}\Theta)$ where E_a and E_b are the two E.M.F's and $\cos(\frac{1}{2}\Theta)$ is the cosine of one-half the angle of difference in phase. For example: We had (Q. 316) two E.M.Fs. of 100 volts, 45 degrees ($\frac{1}{8}$ cycle) apart. Applying the above formula: $E_a + E_b$ is 200; $\frac{1}{2}$ of Θ is $22\frac{1}{2}$ degrees, hence the cosine* of $(\frac{1}{2}\Theta)$ is .92388. Then we have $200 \times .92388 = 184.776$, while the diagram gave 185 as the resultant E.M.F. E_r. The formula is more accurate, of course, as fine diagram measurements are impracticable, even when one is expert enough to draw the diagram with accuracy. When the angle is greater than 90 degrees, however, its complement must be taken.

Q. 321—Does this formula also apply to E.M.F's of different strengths and different phases?

A.—No; the formula for such cases is

$$E_r = \sqrt{(E_a^2 + E_b^2) + (2 \times E_a \times E_b \times \cos.\Theta)}$$

These formulæ are tedious to apply, particularly the latter one. Table IV will enable one to ascertain the resultant of the two E.M.F's, or two currents differing in phase, by making a few simple computations as explained at the foot of the table.

* Ascertained from a table of sines and cosines.

Q. 322—Is an alternator field magnet excited like that of a direct-current dynamo?

A.—Yes and no. It is excited in the same way—by passing direct current through the coils; but this current, of course, continuous current through the coils; but this current, of course, cannot be taken from the alternator brushes. It is supplied by an entirely separate direct-current dynamo, called the "exciter"—usually a 125-volt dynamo.

TABLE IV.

For ascertaining the resultant of two E.M.Fs. in series or two currents in parallel. The smaller of the two, × the figure in the body of the table = the resultant

Ratio.*	Difference of phase between the two E.M.Fs. or currents, in circular degrees.				Ratio.*
	30° or 150°	45° or 135°	60° or 120°	90°	
1§	1.9319	1.8478	1.7321	1.4142	1§
1.05	1.9802	1.8940	1.7755	1.45	1.05
1.1	2.0286	1.9406	1.8193	1.4866	1.1
1.15	2.0771	1.9872	1.8635	1.5241	1.15
1.2	2.1257	2.0339	1.9079	1.5621	1.2
1.25	2.1743	2.0809	1.9526	1.6008	1.25
1.3	2.2229	2.1281	1.9975	1 6401	1.3
1.35	2.2717	2.1752	2.0427	1.68	1.35
1.4	2.3205	2.2226	2.0881	1.7205	1.4
1.45	2.3694	2.2700	2.1337	1.7614	1.45
1.5	2.4183	2.3176	2 1794	1.8028	1.5
1.55	2.4672	2.3653	2.2254	1.8446	1.55
1 6	2.5162	2.4130	2.2716	1.8868	1.6
1.65	2.5652	2.4609	2.3179	1.9294	1.65
1.7	2.6143	2.5088	2.3643	1.9723	1.7
1.75	2.6634	2.5568	2.4109	2.0156	1.75
1.8	2.7125	2.6049	2.4576	2.0591	1.8
1.85	2.7617	2.6531	2.5045	2.1029	1.85
1.9	2.8108	2.7013	2.5515	2.1471	1.9
1.95	2.8601	2 7496	2.5985	2.1915	1.95
2.	2.9093	2 7979	2.6458	2.2361	2.
2.1	3.0079	2.8948	2.7404	2.3259	2.1
2.2	3.1065	2.9919	2.8355	2.4166	2.2
2.3	3.2053	3.0891	2.9309	2.508	2.3
2.4	3.3041	3.1865	3.0265	2.6	2.4
2.5	3.4029	3 2841	3.1225	2.6926	2.5

* The larger E.M.F. or current ÷ the smaller, thus $\frac{E}{e}$ or, $\frac{C}{c}$.

§ Equal E.M.Fs. or currents.

Q. 323—Why cannot a commutator be put on to give continuous current for the field?

A.—Because of the vicious sparking that would occur. Such a commutator is used occasionally to pass the main current through series field coils, in order to secure the same effect as that of the compound field winding on a direct-current dynamo.

The connections are as in Fig. 182, from which it will be seen that the commutator here, *c*, is arranged differently from the commutator of a direct-current dynamo. To distinguish between them this device is called a rectifier. The rectifier is shown off to one side in the cut for the sake of clearness. In the actual machine it is mounted on the shaft beside the collector rings.

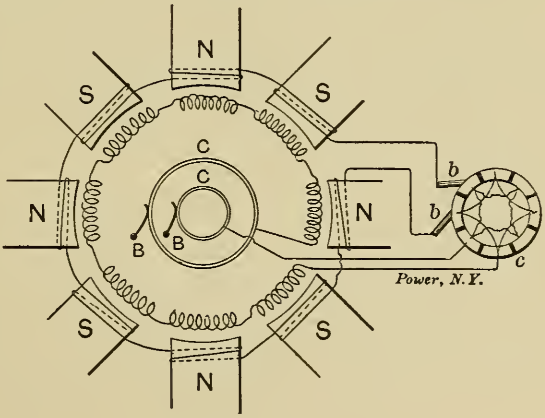


FIG. 182.

Q. 324—What are the wires inside the commutator for?

A.—To show that alternate segments are connected together. In practice, wires are not used; the commutator, or rectifier, is built in two parts like a dental clutch coupling, with insulation between the two halves. Fig. 183 shows this construction. The total number of teeth or segments must equal the number of poles on the field magnet, so that the connections between the armature and field windings will be reversed every time a coil passes from pole to pole.

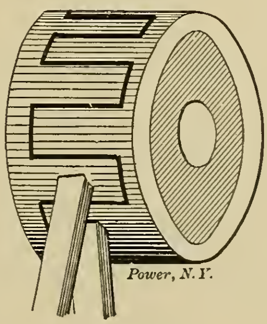


FIG. 183.

Q. 325—In Fig. 182 only one set of field coils is shown. How is the exciter connected?

A.—Fig. 184 is a diagram of all of the field connections where

series coils and a rectifier are used. In polyphase (two or three-phase) machines, and in a great many simple alternators, rectifiers are not used.

Q. 326—Why would a rectifier spark worse if all of the field coils were supplied through it?

A.—Because the brushes would then short-circuit the whole armature every time they touched two segments, as shown by Fig. 185, which shows the way the connections would be made. As the brushes pass from segment to segment the field coils and armature winding are both short-circuited. In Fig. 184 only the field coils can be short-circuited.

Q. 327—But does not this occur when the armature coils are in neutral position?

A.—Yes; so far as the generation of E.M.F. is concerned. But

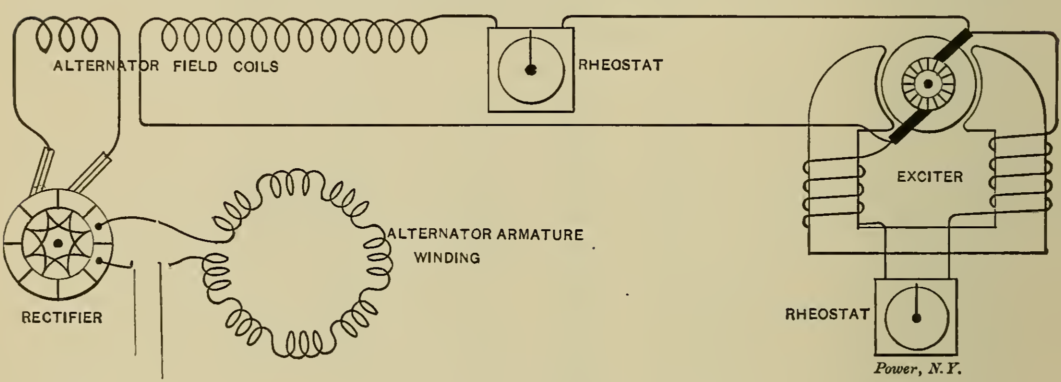


FIG. 184.

even when the armature coils are cutting no lines of force there is quite an appreciable current flowing through them under usual conditions.

Q. 328—How can current exist when the E.M.F. is zero, as it is between each reversal?

A.—Because the current strength does not usually rise and fall precisely with the E.M.F., but "lags" behind it a greater or lesser amount, according to circumstances. Fig. 186 shows the way the rise and fall of the current "lags" behind that of the E.M.F.* Now, if the brushes short-circuit the armature at the instant *A*,

* The amount of difference in phase between current and E.M.F. is called the "angle of lag," and measured in degrees of a circle, exactly like the difference phase of two E.M.F.'s or currents, a complete cycle being represented by a circle, as previously explained.

when the generated E.M.F. is zero, the current will not be zero, but will have considerable strength, as represented by the distance from the zero line up to the current curve along the line *A*. Then when the rectifier segment passes beyond the brush the path through which the current has been flowing from segment to segment will be broken and a serious flash will result.

Q. 329—What happens when the brush touches both segments at the instant the current is zero?

A.—That instant is represented by the vertical line *V*, in Fig. 186, which shows that the E.M.F. generated then would be con-

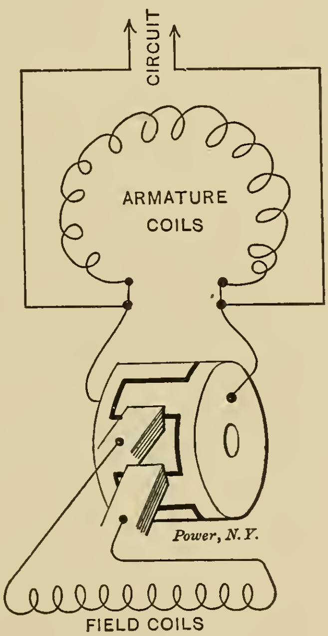


FIG. 185.

siderable; hence, though the current in the outside circuit would be zero, the E.M.F. short-circuited in the armature would set up a separate heavy current through the armature wires, which would be interrupted when the brush left the segment, causing a destructive flash. The diagram shows a current "lag" of about $\frac{1}{20}$ cycle, or 18 degrees, which is frequently present in practice. At this amount of lag the E.M.F. has $\frac{3}{10}$ of its maximum value when the current is zero; similarly, the current strength is $\frac{3}{10}$ of its maximum when the E.M.F. is zero. For example, if a 2,000-volt alternator were supplying 50 amperes, with the lag shown, the instantaneous value of the E.M.F. at *V* would be

$848\frac{1}{2}$ volts ($\frac{3}{10}$ of 2,828.4 volts; see Q. 217). Short-circuiting an armature under such an E.M.F. would set up a tremendous current in the windings. If, on the other hand, we "commutate"† at *A*, when the armature is zero, the armature current will be $25\frac{1}{5}$ amperes; and although it is better to short-circuit this current than to short-circuit the $848\frac{1}{2}$ volts of E.M.F., the flashing at the brushes would be pretty vicious.

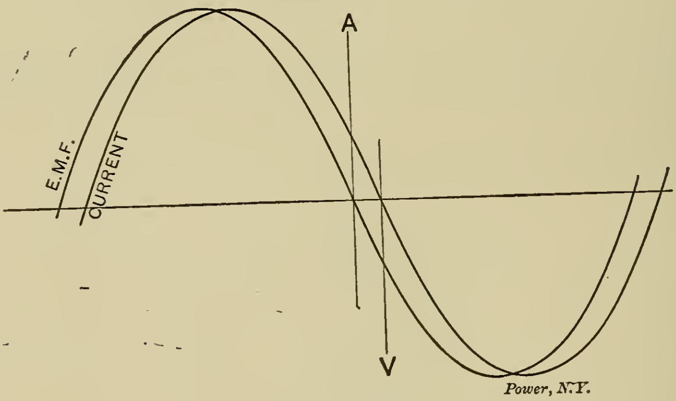


FIG. 186.

Q. 330—Why cannot the current be made to rise and fall in phase with the E.M.F.?

A.—Because it is retarded by self-induction, which is present in nearly every alternating-current circuit.

†When the brush passes from one segment to the other the current is "commutated."

CHAPTER IX.

ALTERNATING CURRENT PRINCIPLES.

Q. 331—What is self-induction?

A—The magneto-electric inductive action of an electro-magnet. Therefore, any circuit including electro-magnets will show more or less self-induction when an alternating curent passes through it.

Q. 332—What causes the inductive action?

A.—The cutting of its own lines of force by the wires of the

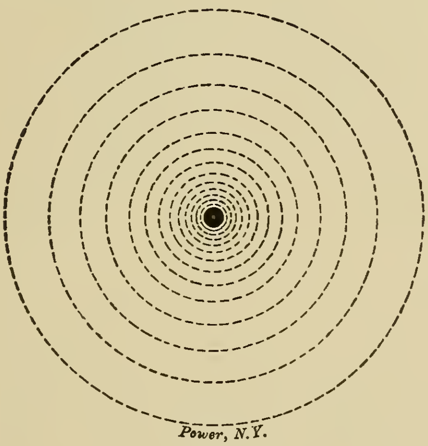


FIG. 187.

magnet coil. This generates an E.M.F. in opposition to the E.M.F. of the dynamo and "chokes" back, or retards, the current flow.

Q. 333—How can the lines of force passing from pole to pole of a magnet be cut by the wires wound on the core of the magnet?

A.—Figs. 187 to 190 will show. Passing a current through a wire creates lines of force which form closed loops or circles around the wire, as indicated by Fig. 187. These magnetic loops or circles do not suddenly spring into existence in their position of maximum strength, but develop from a central point (the

center of the wire), expanding into larger and larger circles as the exciting current increases in strength, until it reaches maximum. When the current begins to decrease in strength the magnetic circles collapse successively, each finally vanishing at the central point when the exciting current is zero. The wave circles formed by dropping a stone in a pool of water illustrate the expanding action of the magnetic lines. Their contraction, or collapse, is simply the reverse of this. Now, if several wires, all carrying current, be put together the magnetic loops created by them will unite into one set of loops circling around the general center of the group, as in Fig. 188, where the dot represents the "center of propagation." It is clear that when the lines of force expand outward from the central point they are cut by all

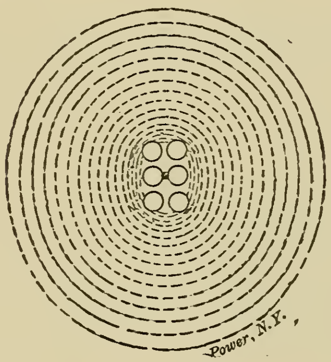


FIG. 188.

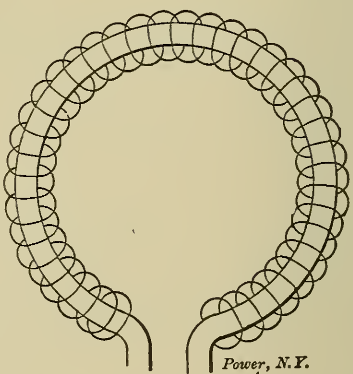


FIG. 189.

of the wires of the group, and when they collapse they are cut by the wires in the opposite direction. As previously explained, E.M.F. is induced by cutting lines of force with a conductor, irrespective of whether the lines are stationary and the conductor moves, or the conductor is stationary and the lines move (sidewise). In this case the conductor is fixed and the lines move past it and back again, inducing an E.M.F. opposite in direction to the E.M.F. which drives the current through the wires, but not so great, of course, in value.

Q. 334—But what has this to do with an electro-magnet?

A.—The magnetic lines circle around the wires of the magnet coil just as they would around a group of straight wires. For example, if the single wire of Fig. 187 were bent into a ring the magnetism would circle around it, as in Fig. 189, just the same.

And the magnetic loops about any section of a coil of wire are the same as though the wires were straight, as shown in Fig. 190. At the instant of time represented in the cut the lines are flowing from top to bottom in the core. Now, when the current in the coil falls to zero the lines of force collapse, cutting across the wires of the coil and inducing an E.M.F. in it. The action takes place twice in every cycle, and is called "self-induction," because the lines of force created by the coil induce an E.M.F. in it.

Q. 335—How much E.M.F. is induced in the coil?

A.—That depends upon the number of turns of wire, the number of lines of force, and the frequency (number of cycles per second). The value of this E.M.F., called the *inductive* or reactive

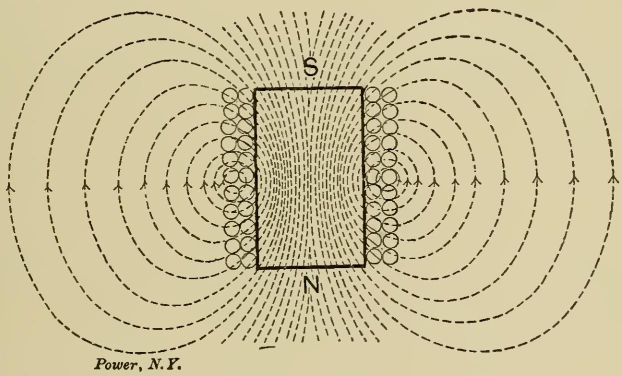


FIG. 190.

E.M.F., is found by a formula similar to that for continuous-current E.M.F., namely,

$$E_i = \frac{1.11 \times \Phi \times N \times f}{25,000,000} \text{ or } \frac{\Phi \times N \times f}{22,522,522.5} \qquad (28)$$

In this formula Φ represents the maximum number of magnetic lines created; N is the number of complete turns of wire; and f is the number of cycles per second. The inductive E.M.F. may be also calculated as below:

$$E_i = 2\pi \times C \times f \times L \qquad (29)$$

Here L represents the "inductance" of the coil.

Q. 336—What is meant by the inductance?

A.—The coefficient of self-induction. In formula shape,

$$L = \frac{\Phi \times N}{141,421,360 \times C} \qquad (30)$$

Here Φ and N retain the significance given under Q. 335, and C

is current, of course. The relation between formula (28) and formula (29) may be seen by including formula (30) in formula (29), thus:

$$E = 6.2832 \times C \times f \times \frac{\Phi \times N}{141{,}421{,}360 \times C}$$

which reduces to formula (28), thus:

$$E_i = \frac{\Phi \times N \times f}{22{,}522{,}522.5225}$$

Q. 337—Does not the inductive E.M.F. in opposition to the dynamo E.M.F. offset part of it?

A.—Yes. It neutralizes part of the impressed E.M.F., and the result is that the amount of current that flows through the coil is much smaller than it would be if the current were not alternating. The inductive E.M.F., however, is not fully opposed to the impressed E.M.F.,* so that it does not neutralize its full value in the latter.

Q. 338—Why is it not fully opposed to the impressed E.M.F.?

A.—Because it always lags 90 degrees behind the current, and the current lags behind the E.M.F. less than 90 degrees. If the current lagged 90 degrees the inductive E.M.F. would be 180 degrees, or ½ cycle, behind the impressed E.M.F., and thus oppose it squarely. As it is, its opposition is exactly similar to the opposition of one mechanical force against another at an angle, so that its full force is not presented against the impressed force.

Q. 339—How may the amount of opposition be computed?

A.—The amount of direct opposition is not usually computed. The value of what remains available of the impressed E.M.F. is the essential one, because it is that that forces the current through. It may be found as follows:

Subtract the square of the inductive E.M.F. from the square of the impressed E.M.F. and take the square root of the remainder. This root will be the E.M.F. actually available for work.

Thus:

$$\sqrt{E^2 - E_i^2} = E_a$$

This available E.M.F., E_a, is called "active" E.M.F., because it alone forces current through the coil. If for any reason one de-

* Impressed E.M.F. is the E.M.F. supplied by some outside source, as distinguished from the inductive or back E.M.F. of the coil.

sired to know the effectual oposition of the inductive E.M.F., simply subtracting E_a from E will give it. It must be remembered, however, that the effectual opposition thus obtained is not the full value of E_1.

Q. 340—Can the active E.M.F. be ascertained without knowing the inductive E.M.F.?

A.—Easily, if the resistance of the coil or circuit is known. Then $C \times R = E_a$. And the inductive E.M.F. can also be found by the formula

$$E_i = \sqrt{E^2 - (C \times \mathrm{R})^2},$$

obviating the calculations given under Q. 635 and 636.

Q. 341—Is not the formula $C \times R = E_a$ like Ohm's law?

A.—Exactly. The current $\times$ the resistance equals the E.M.F. that actually forces it through. Or, the current is equal to the E.M.F. actually available to force it through a resistance, divided by that resistance. Thus,

$$\frac{E_a}{R} = C.$$

Q. 342—Then the product of $C \times R$ does not equal the dynamo E.M.F., like it does in continuous current work?

A.—No, because part of the dynamo current is neutralized, and therefore not available. Looking at it from another direction, however, we can apply the principle of Ohm's law to the impressed E.M.F. by taking into consideration *all* of the opposition encountered by the impressed E.M.F., instead of merely the resistance. This resistance, R, of the magnet coil opposes the current flow, and the self-induction also opposes it, but without loss of energy. Now, these two effects—resistance and "reactance" (called so because the self-induced E.M.F. reacts on the impressed E.M.F.)—added together at any instant, give the total opposition at that instant to the current flow. This total opposition is called "impedance," and is represented by Z.

Impedance is equal to the square root of the sum of the squares of the resistance and reactance. Thus,

$$\sqrt{\text{Reactance}^2 + \text{Resistance}^2} = \text{Impedance; or,}$$

$$\sqrt{X^2 + R^2} = Z.$$

As Z represents the total opposition to the current flow, we can write

$$\frac{E}{Z} = C, \text{ and } \frac{E}{C} = Z, \text{ and } C \times Z = E;$$

which is plainly in accord with the principle of Ohm's law.

Q. 343—In what units are reactance and impedance measured?

A.—In ohms, like resistance. R is the resistance in ohms due to the material of the conductor; X is the resistance in ohms due to self-induction, and is called reactance chiefly to distinguish it from the other resistance, and incidentally because it conveys an idea of the character of the inductive opposition. Z is the combined effect of these two, in ohms.

Q. 344—How can the reactance and impedance of a coil or circuit be ascertained?

A.—By simple measurements, if current is flowing. As $E \div C = Z$, the impedance may be found by dividing the E.M.F. by the current. And as $\sqrt{R^2 + X^2} = Z$, $Z^2 = R^2 + X^2$; so that, having found Z, subtracting R^2 from its square gives the square of the reactance, or X^2. Thus, if a coil has 10 ohms resistance and an alternating E.M.F. of 500 volts applied at its terminals forces only 20 amperes through, it is evident that there is reactance present, because if there were only resistance the current would be $\frac{500}{10} = 50$ amperes. $E \div C = Z$, so the *impedance* of this coil would be $\frac{500}{10} = 25$ ohms; and as the resistance is 10 ohms, the reactance is $\sqrt{25^2 - 10^2}$, or $\sqrt{625 - 100}$, which is 22.9 ohms.

Q. 345—Suppose the resistance is not known?

A.—Then the reactance is extremely difficult to obtain. Mathematically it is equal to the self-inductive E.M.F. divided by the current, or

$$\frac{E_i}{C} = X; \text{ and } \frac{E_i}{X} = C; \text{ and } C \times X = E_i.$$

But the value of E_i is not easy to ascertain in practical work unless the resistance is known (see Q. 340), as it depends upon the maximum number of magnetic lines passing through the core of the magnet.

Q. 346—What is the difference between self-inductive E.M.F. and reactance?

A.—Reactance is the equivalent, in ohms, of the resistance through which the self-inductive E.M.F. would force the current.

Thus, if the current, C, were 20 amperes, and the resistance, R, were 40 ohms, and the reactance, X, were 35 ohms, the active E.M.F., E_a would be $C \times R = 20 \times 40 = 800$ volts, and the inductive E.M.F., E_i would be $C \times X = 20 \times 35 = 700$ volts. According to the answer to Q. 339, the impressed E.M.F., E, is equal to $\sqrt{E_i^2 + E_a^2}$. This would make it 1,000 volts in this case. And as $E \div C = Z$, the impedance must be $1{,}000 \div 20 = 50$ ohms. Checking this by the formula (33), $Z = \sqrt{R^2 + X^2}$, we have $\sqrt{40^2 + 30^2} = 50$, which agrees perfectly.

Q. 347—Why do the values of E, E_a, E_i, X and R have to be squared in calculating their relations?

A.—Because their relations are exactly analogous to those of mechanical forces combined at an angle and their resultant force. If we have two forces at right angles, as *a*, *i*, Fig. 191, acting upon a common point, the combined influence at the point will be in

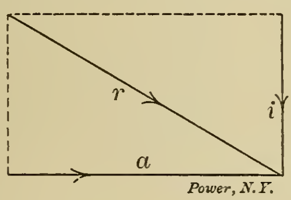


FIG. 191.

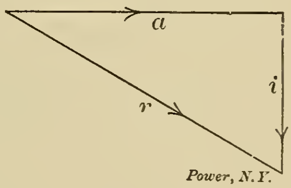


FIG. 192.

the direction of *r*, according to the parallelogram of forces. And if the length of each line, *a* and *i*, be proportional to the force it represents, *r* will be proportional to the resultant force. Now, if *a* represents the active E.M.F. and *i* the E.M.F. of self-induction, then *r* will represent the total or impressed E.M.F.

Q. 348—How does this account for the squares?

A.—A study of the transposed lines in Fig. 192 will show. It makes no difference whether a force be imagined as pulling upon a point or pushing against it; the result is the same if the effort is in the same direction. Fig. 192 shows the force *i* pulling instead of pushing, so that the two forces and their resultant form a right-angle triangle. And "the square of the hypothenuse (*r*) of a right-angle triangle is equal to the sum of the squares of the other two sides." Hence, if *a* represents E *i* represents E and *r* represents E, then

$$E^2 = E^2 + E^2 \text{ and } E = \sqrt{E_a^2 + E^2}$$

Q. 349—Are E_a and E_i always at right angles with each other?

A.—Yes; invariably.

Q. 350—How about Z and X and R?

A.—Resistances may be considered exactly like forces. In mechanics they are considered so. And as the dead resistance of R is opposed to E_a and the inductive resistance X to E_i these two, R and X, may be considered as active forces at right angles, like a and i, Figs. 191 and 192. Their resultant resistance (impedance, Z) is as r. Hence, $Z^2 = R^2 + X^2$, or $Z = \sqrt{R^2 + X^2}$. Fig. 193 shows these relations. For practical purposes it is more intelligible to simply consider that the inductive E.M.F. neutralizes part of the impressed E.M.F., leaving the active E.M.F. available for work.

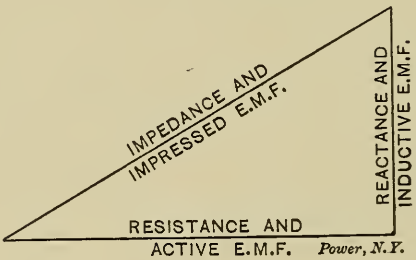


FIG. 193.

Q. 351—Is the E.M.F. neutralized by the inductive E.M.F. wasted?

A.—No; it is rendered useless, but no energy is wasted thereby. The result of the neutralizing impressed volts of E.M.F. with inductive volts of E.M.F. is the same as though neither existed, so far as the work done is concerned. A mechanical analogue would be afforded by two locomotives of equal power, head to head, each trying to push the other backward. Each might be exerting a pressure of many tons against the other, but no work would be done (assuming, of course, that the wheels could not slip on the rails).

Q. 352—As the inductive E.M.F. neutralizes part of the impressed E.M.F., how can one ascertain the number of watts supplied to a magnet coil?

A.—The watts in any circuit are the product of the current and the E.M.F. that forces it through. In alternating current work

this E.M.F. is the active E.M.F., E_a previously explained. Therefore, E_a, $\times C = W$.

Q. 353—What is obtained by multiplying the impressed E.M.F. by the current?

A.—The "apparent" watts, which may be represented by $W?$; so-called because they represent the power which *seems* to be applied. The actual power is called "true" watts, or "real" watts, which are the product of E_a and C, as above. If one knows how much the current lags (see answer to Q. 328) behind the E.M.F. (impressed), the real watts may be calculated by the formula:

Imp. E.M.F. $\times$ Current $\times$ cosine of θ = Watts; or Appar. Watts $\times$ cosine of θ.

$E \times C \times \cos\theta = W$; or $W? \times \cos\theta = W$.

Here the symbol Θ represents the number of degrees of a circle by which the current hangs back in its rising and falling, as compared with the rising and falling of the E.M.F., *i. e.*, the "angle of lag."

Q. 354—How may the angle of lag be ascertained?

A.—If the resistance of the circuit or coil be known, the cosine of the angle of lag may be easily found by the formula

$$\frac{C \times R}{E} = \cos\theta.$$

From a table of sines and cosines the value of Θ can be readily found.

Q. 355—Can the angle of lag be measured?

A.—Not directly, but its cosine can be obtained by measuring the true watts with a wattmeter (not a watt-hour meter) and the apparent watts with a voltmeter and ammeter, and dividing the one by the other. For example, if the wattmeter indicates 1,600, the voltmeter 100 volts and the ammeter 20 amperes, the true watts will be 1,600 and the apparent watts $100 \times 20 = 2{,}000$. The ratio between the two is $\frac{1600}{2000} = 0.8$, which will be the cosine of the number of degrees by which the current hangs back behind the E.M.F.

Q. 356—Why does not the wattmeter indication agree with the product of the voltmeter and ammeter indications?

A.—Because it will only indicate the true or real watts, and the product of the $E \times C$ gives the apparent watts.

Q. 357—Why does dividing the real watts by the apparent watts give the cosine of the angle of lag?

A.—Because the real watts $= E \times C \times \cos \Theta$ and the apparent watts

$$\frac{E \times C \times \cos \theta}{E \times C} = \frac{E \times C}{E \times C} \times \cos \theta = 1 \times \cos \theta = \cos \theta$$

Cos Θ is equivalent to what is known as the "power factor" of a circuit or apparatus in which the current lags Θ degrees behind the E.M.F.

Q. 358—What is meant by power factor?

A—The ratio between the true watts and the apparent watts, or the proportion of the apparent watts that is available for power. In formulas it is represented by either cos Θ or the letter p.

Impress. E. M. F.	= $\sqrt{\text{Induc. E.M.F.}^2 + \text{Act. E.M.F.}^2}$,	or $E = \sqrt{E_i^2 + E_a^2}$
Imp. E. M. F.	= Induc. E.M.F. ÷ sine of lag angle,	or $E = E_i \div \sin\theta$
Imp. E. M. E.	= Act. E.M.F. ÷ cosine of lag angle,	or $E = E_a \div \cos\theta$
Imp. E. M. F.	= Current × Impedance,	or $E = C \times Z$.
Inductive E. M. F.	= $\sqrt{\text{Imp. E. M. F.}^2 - \text{Act. E.M.F.}^2}$,	or $E_i = \sqrt{E^2 - E_a^2}$
do	= Imp. E.M.F. × sine of lag angle,	or $E_i = E \times \sin\theta$
do	= Current × Reactance,	or $E_i = C \times X$.
do	= 2 π × Frequency × Inductance × Current,	or $E_i = 2\pi \times f \times L \times C$
Active E. M. F.	= $\sqrt{\text{Imp. E.M.F.}^2 - \text{Induc. E.M.F.}^2}$,	or $E_a = \sqrt{E^2 - E_i^2}$
do	= Imp. E. M. F. × cosine of lag angle,	or $E_a = E \times \cos\theta = E \times p$
do	= Current × Resistance,	or $E_a = C \times R$.
do	= True watts ÷ Current,	or $E_a = W \div C$.
Current	= True watts ÷ Active E. M. F.,	or $C = W \div E_a$
do	= $\sqrt{\text{True watts} \div \text{Resistance}}$,	or $C = \sqrt{W \div R}$.
do	= Imp. E. M. F. ÷ Impedance,	or $C = E \div Z$.
do	= Induc. E. M. F. ÷ Reactance,	or $C = E_i \div X$.
do	= Active E. M. F. ÷ Resistance,	or $C = E_a \div R$.
Impedance	= $\sqrt{\text{Resistance}^2 + \text{Reactance}^2}$,	or $Z = \sqrt{R^2 + X^2}$
do	= Resistance ÷ cosine of lag angle,	or $Z = R \div \cos\theta$ or $\frac{R}{p}$
do	= Reactance ÷ sine of lag angle,	or $Z = X \div \sin\theta$
do	= Imp. E. M. F. — Current,	or $Z = E \div C$.
Resistance	= $\sqrt{\text{Impedance}^2 - \text{Reactance}^2}$,	or $R = \sqrt{Z^2 - X^2}$
do	= Impedance × cosine of lag angle,	or $R = Z \times \cos\theta$ or $Z \times p$
do	= Act. E. M. F. ÷ Current,	or $R = E_a \div \theta$.
do	= Real watts ÷ Current,	or $R = W \div C$.
Reactance	= $\sqrt{\text{Impedance}^2 - \text{Resistance}^2}$,	or $X = \sqrt{Z^2 - R^2}$
do	= Induc. E. M. F. ÷ Current,	or $X = E_i \div C$.
do	= Impedance × sine of lag angle,	or $X = Z \times \sin\theta$
do	= 2 π × Frequency × Inductance,	or $X = 2\pi \times f \times L$.
Inductance	= $\dfrac{\text{Magnetism} \times \text{No. of wires}}{1{,}414{,}214 \times \text{current}}$,	or $L = \dfrac{\Phi \times N}{1{,}413{,}214 \times C}$
App. watts	= Imp. E. M. F. × Current,	or $W? = E \times C$.
do	= Current² × Impedance,	or $E \times C = C^2 \times Z$.
True Watts	= Imp. E. M. F. × Current × power factor,	or $W = E \times C \times \cos\theta$
do	= Current × Impedance × power factor,	or $W = C^2 \times Z \times \cos\theta$
do	= Active E. M. F. × Current,	or $W = E_a \times C$.
do	= Current² × Resistance,	or $W = C^2 \times R$.
Power factor	= Resistance ÷ Impendance,	or $p = \text{Cos}\,\theta = R \div Z$.
do	= Active E. M. F. ÷ Impress. E. M. F.,	or $p = \text{Cos}\,\theta = E_a \div E$.
Sine of Lag Angle	= Induc. E. M. F. ÷ Imp. E.M.F.,	or $\text{Sin}\,\theta = E_i \div E$.
do	= Reactance ÷ Impedance,	or $\text{Sin}\,\theta = X \div Z$.

CHAPTER X.

TRANSFORMERS.

Q. 359—Why is alternating current used when direct current is so much simpler?

A.—Because of the ease with which a high E.M.F. can be generated and changed to a lower or higher E.M.F.

Q. 360—Of what advantage is this?

A.—It permits the transmission of large power to a great distance economically. The higher the E.M.F. the less the current for a given amount of power, consequently the smaller the line wire may be for a given loss, or the smaller the loss with a given size of wire. For example, 1,000 kilowatts at 2,000 volts demand a current of only 500 amperes; if the E.M.F. were 500 volts the current would be 2,000 amperes. Now, suppose we had a line that transmitted 500 amperes with a drop of 100 volts, or 5 per cent. The drop with 2,000 amperes would be 400 volts, or 80 per cent of the available E.M.F. of 500 volts. Hence, to transmit the 1,000 kilowatts at 500 amperes with a loss of 5 per cent, the line would have to be sixteen times as heavy as it would with an E.M.F. of 2,000 volts.

Q. 361—Cannot direct current be generated at high potentials?

A.—Yes, up to certain limits. Above 2,000 or 3,000 volts, however, the commutator becomes prohibitively expensive, and it is extremely difficult to obtain smooth commutation at such high potentials. Moreover, the potential is too high to use at the lamps or motors, and to reduce it requires the use of a combined motor and dynamo, the motor winding being designed for the high potential and the dynamo winding for the lower distribution voltage.

Q. 362—How is alternating current E.M.F. lowered?

A.—By means of an apparatus without moving parts, called a "transformer."

Q. 363—What is a transformer like?

A.—It consists of an iron core of thin sheets, on which are wound two sets of coils called the primary and secondary wind-

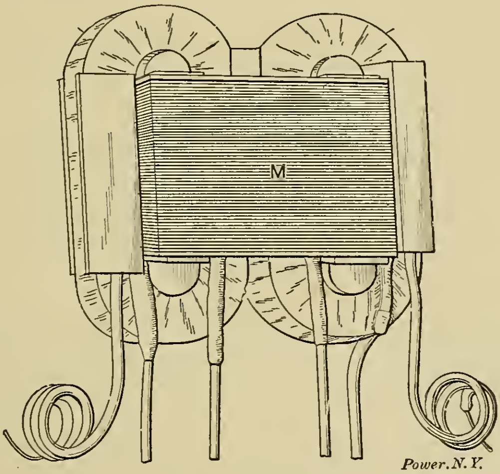


FIG. 194.

ings. Fig. 194 shows one form of transformer, with its case removed, and Fig. 195 shows it complete.

Q. 364—How does a transformer act?

A.—The primary winding, supplied by the high potential mains, creates lines of force in the core, which may be considered to continuously and rapidly expand and contract; these lines are

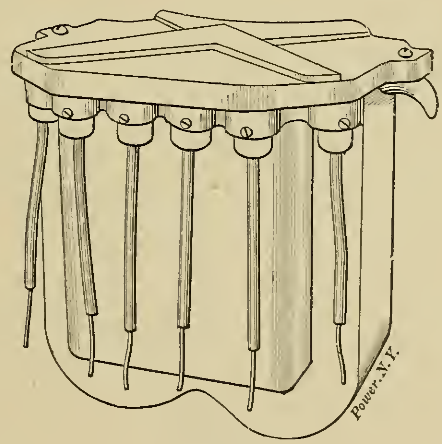


FIG. 195.

"cut" by the secondary wires, and consequently an E.M.F. is induced in the secondary winding, which furnishes current to the low-pressure mains.

Q. 365—How does this change the E.M.F.?

A.—The primary E.M.F. is not changed, but the magnetic lines created by the primary current induce a lower E.M.F. in the secondary windings.

Q. 366—Why is the secondary E.M.F. lower than the primary?

A.=Because the secondary winding has fewer turns of wire than the primary, and the E.M.F. is proportional to the product of wires, flux and frequency. The frequency and flux are the same for both windings, the only difference being the number of wires.

Q. 367—Then the difference between the numbers of turns in the primary and secondary windings determines the difference in E.M.F.?

A.—Yes. And for all practical purposes, the ratio of primary to secondary turns of wires may be considered exactly the same as the ratio of primary to secondary E.M.F's. That is, if the number of turns in the secondary winding is one-tenth the number of turns in the primary winding, the secondary E.M.F. will be one-tenth of the primary E.M.F.

Q. 368—How much lower is the secondary E.M.F. than the primary?

A.—There are several ratios. For ordinary commercial distribution the primary E.M.F. is either 1,000 or 2,000 volts, and the secondary E.M.F. is either 50 or 100 volts, according to preference.* Therefore, the ratio between primary and secondary may be 10 to 1, 20 to 1 or 40 to 1. The most common ratios are 10 and 20 to 1, the primary E.M.F. being 1,000 or 2,000 and the secondary 100 or the primary being either 1,040 or 2,080 and the secondary 104 volts.

Q. 369—How is the output of a transformer determined?

A.—The E.M.F. may be approximately determined from the formula previously given for inductive E.M.F., viz.:

$$E_i = \frac{4.44\, \Phi \times \times N \times f}{100{,}000{,}000} \qquad (31)$$

in which Φ is the maximum magnetic flux in the core; N, the

* To be strictly accurate, some systems use 1,040 and 2,080 volts primary E.M.F. and 52 and 104 volts secondary E.M.F. Others use the even potentials above mentioned.

number of turns in the coil, and f, the frequency (cycles per second) of the supply circuit.

Q. 370—Is this formula for the primary or secondary coil?

A.—It applies to both.

Q. 371—How is the maximum magnetic flux, Φ determined?

A.—It takes care of itself. In making the calculation for the primary coil, the value of E_i may be considered as practically equal to that of the primary line potential. Then the flux may be approximated by the formula

$$\Phi = \frac{E_p \times 100,000,000}{4.44 \times N_p \times f} \quad \text{(32)}$$

in which E_p is the primary E.M.F., N_p the number of turns in the primary coil and f the frequency. The cross section of the core is usually made large enough to bring the magnetic density down to about 20,000 lines per square inch in transformers used on 133 cycle circuits. Several preliminary calculations are necessary before satisfactory proportions are obtained.

Q. 372—Does the secondary winding change the magnetic flux?

A.—Not appreciably. The flux remains at practically the same value for all loads and no load in the secondary coil, as long as the primary E.M.F. is unchanged.

Q. 373—Does not the secondary current and winding tend to magnetize the core?

A.—Yes, in the opposite direction to the primary; consequently, when current is allowed to flow in the secondary, the primary current increases just enough so that the combined effect of the two windings remains the same as the magnetizing effect of the primary alone when the secondary is open.

Q. 374—Are the currents the same in strength?

A.—No; the ampere-turns are practically the same, though. Hence the ratio of primary current to secondary current is the same as the ratio of secondary turns (and E.M.F.) to primary turns (and E.M.F.). Thus, if the primary is wound for 1,000 volts and the secondary for 100 volts the primary turns will be 100 times the secondary turns, and the secondary current will be 100 times the primary current at any and all loads.

Q. 375—What determines the amount of current a transformer can stand?

A.—The size of the wire used in the winding, roughly. More accurately, the resistance of the winding and the effective area of radiating surface.

Q. 376—What effect has the radiating surface upon the current capacity?

A.—The greater the effective radiating surface the less will be the rise in temperature for a given current in a given size of wire. Hence, the greater the radiating surface of a coil, the more current can be passed through it for a given rise in temperature. In ordinary practice the size of the wire forms a sufficiently good guide as to the amount of current allowable.

Q. 377—What area of wire is usually allowed per ampere of current?

A.—Fifteen hundred circular mils per ampere is a fair figure.

Q. 378—What rise of temperature is allowed?

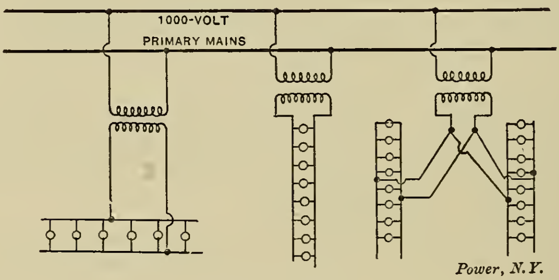


FIG. 196.

A.—There is no uniformity in the rise of temperature. Some transformers show a rise of 30 degrees and some a rise of 130 degrees Fah. A good limit for average conditions is 80 to 90 degrees Fah.

Q. 379—What regulates the amount of current furnished by a transformer?

A.—The resistance of the work circuit, just as in the case of a constant-potential dynamo.

Q. 380—Then the current increases as the resistance of the circuit decreases?

A.—Yes. Overloading is prevented by fuses in both primary and secondary circuits.

Q. 381—Where are the fuses located?

A.—Within pockets either in or near the transformer case.

They are mounted on porcelain bases, similar to the ordinary fuse block, but of special shape to suit the different conditions.

Q. 382—How are transformers connected to the circuits?

A.—The primary winding is connected to the two sides of the primary mains, and the secondary is similarly connected to the secondary work circuit, as in Fig. 196. The secondary terminals of a transformer may be considered as the terminals of a dynamo.

Q. 383—Are the transformer coils wound side by side, as in the diagram?

A.—No; they are wound one over the other on the same part of the core. It is customary to draw them side by side merely to show that they are separate electrically.

Q. 384—Why has the transformer in Fig. 194 six terminals to its coils if there are only two windings?

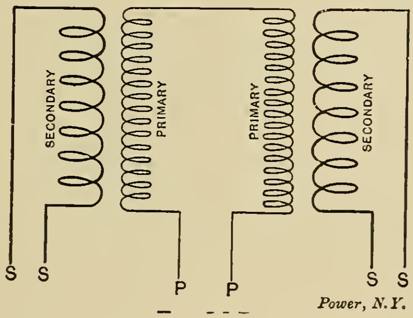


FIG. 197.

A.—Because the secondary winding is divided into two distinct coils, which may be connected in series or in parallel, whereas the two primary coils are connected permanently in series. This arrangement is shown more clearly by the diagram, Fig. 197.

Q. 385—What is the result of changing the connections of the secondary coils?

A.—When connected in series they give twice as great an E.M.F. as when in parallel.

Q. 386—Does not this double the output of the transformer?

A.—No. The output in watts remains unchanged because the current-carrying capacity is divided. Thus, if each coil can stand 10 amperes and generates 50 volts, when connected in series the current capacity is 10 amperes and the E.M.F. $50 \times 2 = 100$ volts. Connected in parallel, the current is 20 amperes and the

E.M.F. 50 volts. Hence, the watts are 1,000 in both cases. See Fig. 198.

Q. 387—Can transformers be worked together, like dynamos, at the secondary ends?

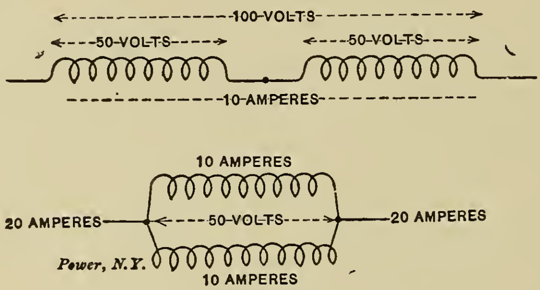


FIG. 198.

A.—Yes; but it is not usually advisable to so work them because several small transformers are less efficient than one large one, and it is seldom practicable to arrange for disconnecting one or more of a group as the load decreases, and putting them back as it increases.

Q. 388—When transformer secondaries are worked together, are they connected in series or in parallel?

A.—They are connected in parallel for ordinary two-wire sec-

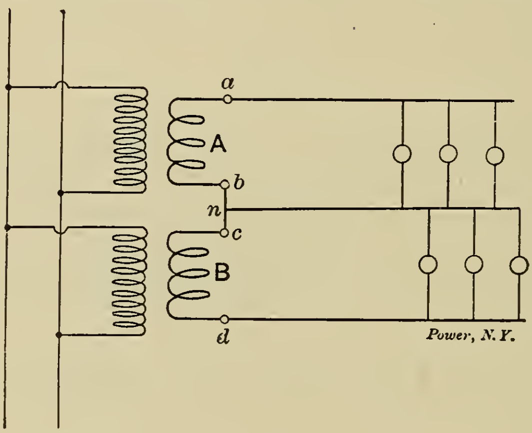


FIG. 199.

ondary circuits. The connections are exactly the same as though the secondaries were dynamo armatures.

Q. 389—Does it make any difference which way transformer terminals are connected to a line?

A.—They can be connected in either way, but they are almost invariably connected in parallel.

Q. 390—Can they be arranged to supply a three-wire system?

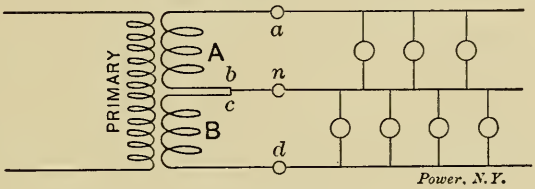


FIG. 200.

A.—Yes. If they are worked together the same precautions must be taken as in the case of continuous-current dynamos—

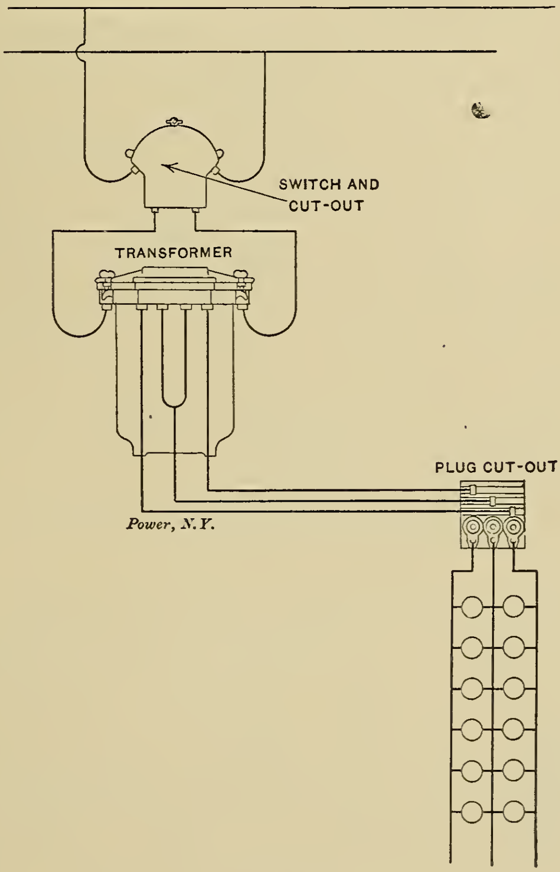


FIG. 201.

namely, for parallel grouping, like terminals, must be connected together, while for three-wire and series working, unlike terminals must be connected to each other. Fig. 199 is a diagram of two

transformers connected up for three-wire secondary service, and Fig. 200 is a diagram of a single transformer with its two secondaries connected to a three-wire circuit. Fig. 201 is a semi-pictorial diagram of this latter arrangement.

Q. 391—Has alternating-current apparatus any positive and negative terminals?

A.—Not constantly, of course, because the polarity changes several thousand times a minute. The polarity at any given instant is what must be considered. For example, if two secondaries are to be connected to three-wire mains, as in Fig. 199, care must be observed to connect them so that when the current is flowing from *a* to *b* in *A* the current in *B* will be flowing from *c* to *d*.

Q. 392—How can one tell which way the current is flowing at any instant?

A.—This cannot be ascertained practically, but it is easy to find

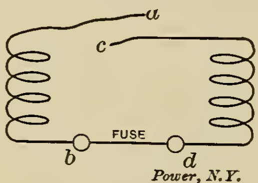


FIG. 202.

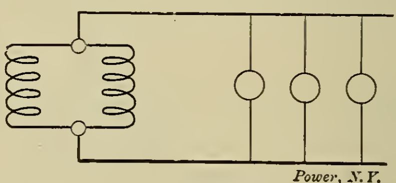


FIG. 203.

out whether the currents in the two secondaries are agreed or opposed by switching on one lamp on each side of the system and disconnecting the neutral wire at *n*, in Fig. 199. If the connections are properly made, the lamps will light; if not, they will not light.

Q. 393—What is the remedy if they don't light?

A.—Simply reverse the connections of *one* secondary.

Q. 394—What precaution is necessary in connecting secondaries in parallel?

A.—Connect two ends with a piece of very small fuse wire (1 ampere), as in Fig. 202. Then touch the remaining end, *a*, of one secondary to the free end, *c*, of the other. If the fuse does not blow, the connections may be made permanent, as in Fig. 203. If it does melt, then the connections must be reversed.

Q. 395—What would happen if the secondary winding were connected to a 50 or 100-volt circuit and the primary winding to another work circuit?

A.—The secondary would then be the primary and induce a high potential in the other winding; if the primary were wound for 1,000 volts, that E.M.F. would be induced in it.

Q. 396—Are transformers ever used this way?

A.—Often. Such a transformer is called a step-up transformer, because the voltage is raised. Step-up transformers are used to raise the generator E.M.F. for long-distance transmission in order to save wire. At the far end of the transmission line step-down transformers bring the line pressure down to a practical E.M.F. for distribution. See Fig. 204. Here the two transformers marked *T* are step-up and step-down transformers, and all those marked *t* are ordinary transformers.

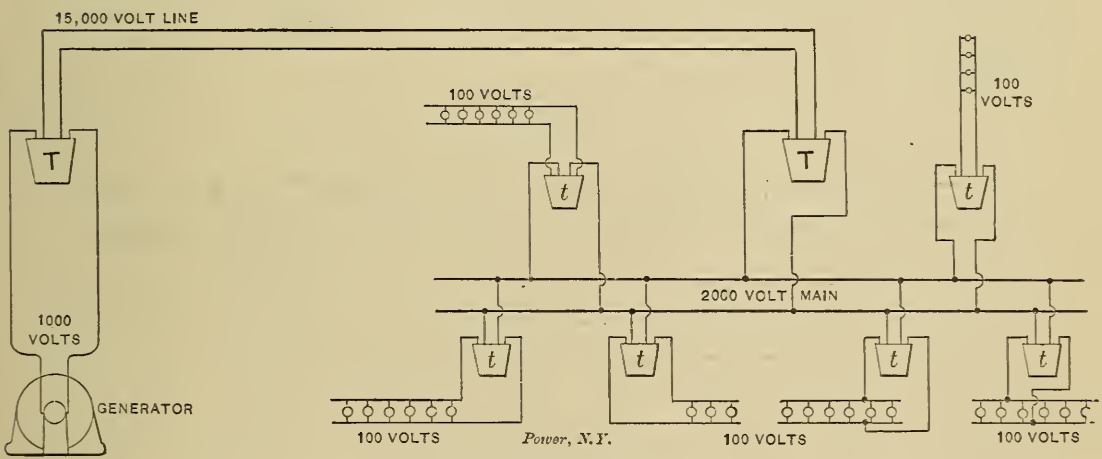


FIG. 204.

Q. 397—What is the difference between step-down transformers and the ordinary kind?

A.—None, in principle. An ordinary transformer is a "step-down" one, but the term "step-down" is applied only to those transformers which are built for high voltage at the secondary end and extremely high voltage at the primary end.

Q. 398—Why cannot the full-line potential be generated and furnished direct to the line by the generator?

A.—It can be, and is, done when the alternator is an inductor machine or has a stationary armature and revolving field magnet. When the more common form of machine (revolving armature) is used, it is inadvisable to generate very high potentials, because of the difficulty of maintaining the armature insulation.

Q. 399—Why is the insulation harder to maintain on a revolving armature than on a stationary one?

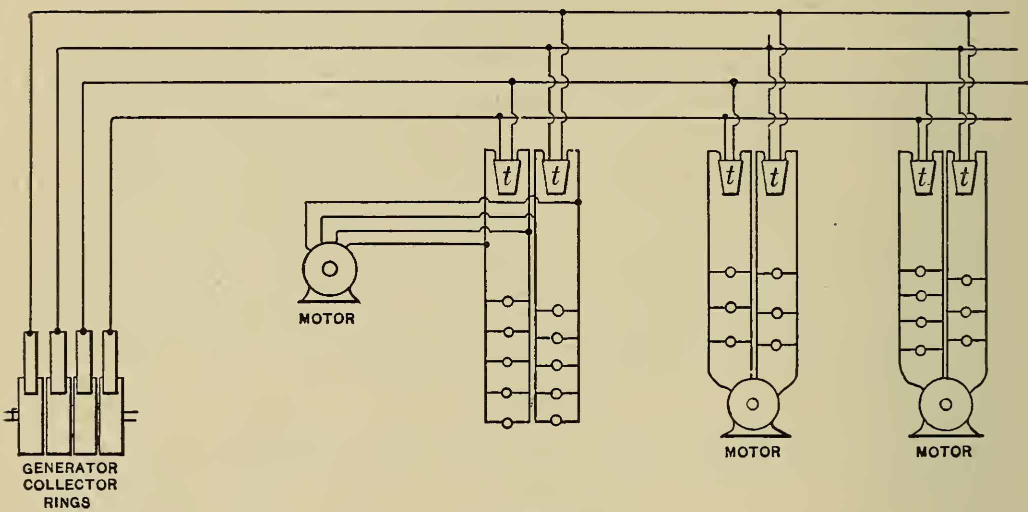


FIG. 205.

A.—Because, primarily, the wires cannot be so securely fastened to a moving core as to a stationary one; and, secondly,

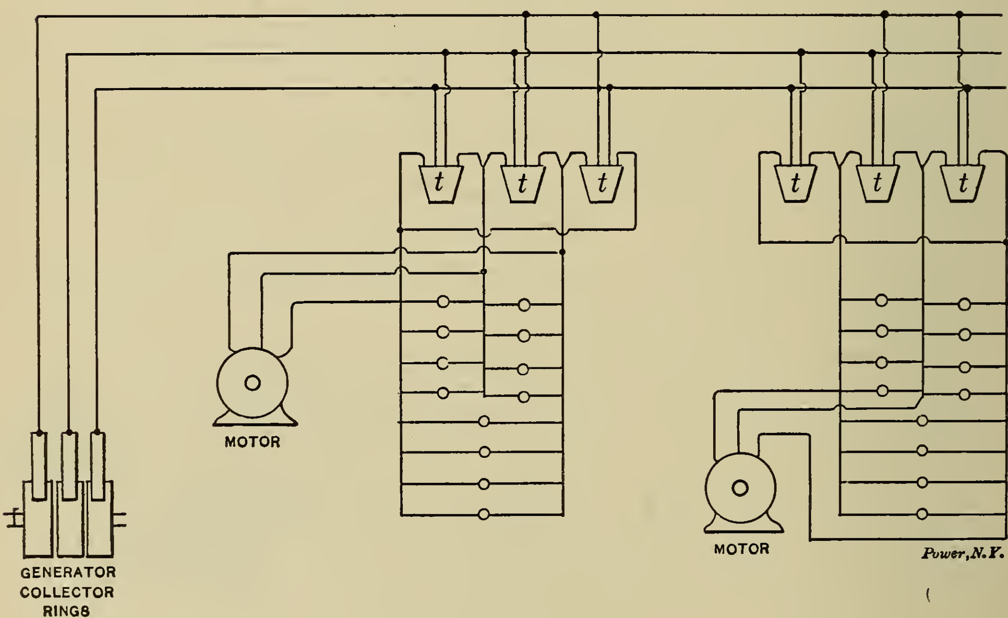


FIG. 206.

the centrifugal effect upon rapidly revolving coils tends to shift them and chafe the insulation.

Q. 400—Are transformers used on polyphase circuits?

A.—Yes, just as on any others.

Q. 401—How are they arranged?

A.—They are connected to the primary wires as though each pair of those wires were a simple alternating-current feeder or main. Fig. 205 shows the connections for two-phase distribution, and Fig. 206 shows typical connections for three-phase distribution; the small circles in both diagrams represent lamps or other translating devices.

CHAPTER XI.

ALTERNATING CURRENT MOTORS.

Q. 402—What is the advantage of polyphase distribution?

A.—The chief advantage is the ability to supply lamps and self-starting motors from the same circuit or from the same character of generator, avoiding a multiplicity of generator types at the station.

Q. 403—Cannot self-starting motors be operated on simple alternating-current lines?

A.—Yes; self-starting single-phase motors are in use, but they do not give quite so satisfactory results as polyphase machines, especially in larger sizes. Moreover, they require special construction or auxiliary apparatus to enable them to be self-starting. A simple single-phase motor, without any special starting device, will not move from a dead rest when thrown into circuit.

Q. 404—Are two-phase and three-phase motors self-starting?

A.—Yes.

Q. 405—Is there any preference between two-phase and three-phase systems?

A.—The three-phase system is more economical in line wires, but a two-phase system is easier to maintain in "balance," and consequently gives better regulation at the generators.

Q. 406—Why is the three-phase system more economical in wire?

A.—Because of the phase relations between the three currents As explained under Q. 300-303, the three currents rise and fall at different instants; the result of this is that the "drop" in a three-wire three-phase line is exactly the same that it would be in a two-phase line having four wires of the same size as those in the three-phase line.

Q. 407—How does it compare with a single-phase line?

A.—Exactly the same way; the amount of copper required in a single-phase two-wire line is the same as that required in a two-

phase four-wire line for the same load and drop—the two wires have each twice the cross-section of each of the four wires of the two-phase line. Therefore, the three-phase three-wire line requires three-fourths the amount of copper for a given set of conditions that is required by the simple alternating-current line with two wires, and also by the four-wire two-phase line.

Q. 408—With the voltage between wires the same in all three systems, how does the current in each wire compare?

A.—The actual amount of power transmitted being the same in all three cases, the current per wire in a two-phase line is one-half that in a single-phase line; the current per wire in a three-phase line is 0.577 of the current in a single-phase line, and 1.155 times the current per wire in a four-wire two-phase line.

Q. 409—How many different kinds of alternating-current motors are there?

A.—There are two general classes, known as synchronous and induction motors; each of these is again divided into single-phase and polyphase.

Q. 410—What is the difference between synchronous and induction motors?

A.—There are two distinctions; a synchronous motor has its field excited from some direct-current source, while its armature takes current from the alternating-current line, whereas an induction motor field is supplied from the alternating-current circuit and its armature is not connected to any source of current, the currents in it being induced by the field—hence its name of "induction" motor. Again, a synchronous motor having a certain number of poles and being supplied with current from an alternator having the same number of poles will run at the same speed as that of the alternator, regardless of the load or voltage—hence the name "synchronous" motor; on the other hand, an induction motor, although tending to run in synchronism with the generator which supplies it with current, cannot do so, but lags behind the generator by a small amount, the actual lag, or "slip" as it is termed, varying with the load on the motor.

Q. 411—Is either type of motor anything like an alternator?

A.—Yes; a synchronous motor is precisely like an alternator. In fact, the two are interchangeable, exactly as in the case of direct-current dynamos and motors.

Q. 412—And does a synchronous motor require a separate exciter, like an alternator?

A.—Yes. In some cases the motor has an individual exciter, either mounted on the end of the motor shaft or belted to it, therefore driven by the motor itself; in other cases, a single exciter dynamo supplies current to the fields of a whole plant or group of synchronous motors, just as in the case of alternating-current generators.

Q. 413—What drives the exciter in the latter case?

A.—It is driven either by one of the motors or by an individual motor devoted solely to that work.

Q. 414—Could not a battery be used for exciting the fields?

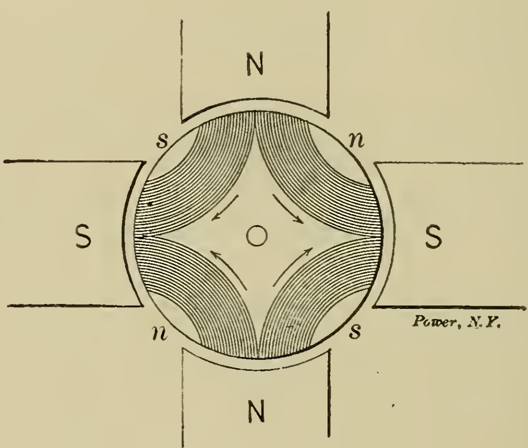


FIG. 207.

A.—Yes, but this is not good practice ordinarily, because of the lack of facilities in an alternating-current plant for charging the batteries.

Q. 415—Why does a synchronous motor run at exactly the speed of the generator supplying current to the circuit?

A.—A consideration of the action of a direct-current motor will assist in understanding this. If the field of the motor be maintained at fixed polarity, the direction in which the armature turns will depend on the direction of the current flow through the armature winding. Reversing the current reverses the direction of rotation. This, as has been explained previously, is because passing a current through a wire lying across a magnetic field causes the wire to be dragged in one direction, and reversing the current

in the wire causes it to be dragged in the other direction. Now, the current in the wires on a synchronous motor armature is constantly reversing, so that if a given group of wires were held near a north magnet pole, say, they would be first attracted toward the pole and then repelled from it. But if the wires are held near a north pole when the current passes in the right direction to cause attraction, and then allowed to move on within reach of the south pole just as the current reverses, the attraction would be continuous in the same direction.

Q. 416—Then each wire must move from one pole to another every time the current reverses, in order to be continuously attracted?

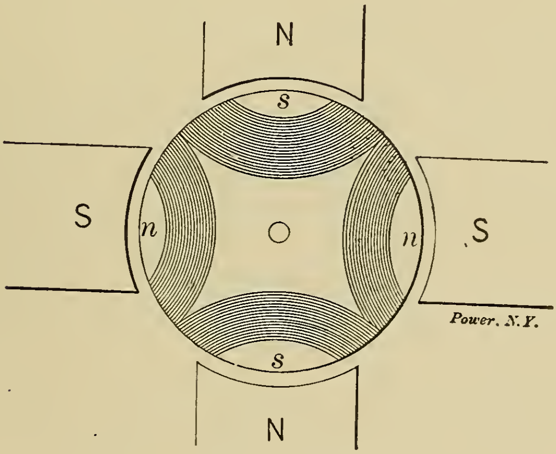


FIG. 208.

A.—Exactly. Reference to Figs. 207 and 208 will make this still clearer. Here the illustration of magnetic pull is used. With current passing through the four armature coils in the directions indicated by arrows in Fig. 207, north poles will be formed at *n* and *n*, and south poles at *s* and *s*, and the armature will be attracted around in the direction taken by clock hands, until the south poles are opposite the north poles of the magnet, as in Fig. 208. At this point a reversal of the current in the armature coils will carry the armature on through another quarter revolution, and so on, it being necessary only to reverse the current every time an armature "pole" comes opposite a field-magnet pole.

Q. 417—How is the motor made to turn at exactly the speed necessary to bring the coils from pole to pole in time with the reversals of the line current?

A.—It is run up to that speed by some outside means and then connected to the circuit; afterward, the pull between the field poles and the armature will keep the speed up, unless the machine be overloaded.

Q. 418—Then a synchronous motor is not self-starting?

A.—It is to a certain extent, but the flow of current through the armature is extremely heavy during the starting, which is not due to direct magnetic pull between the magnet poles and the armature poles, but to a complicated reaction between the two which is highly inefficient and cannot be explained to anyone who is not throughly versed in alternating-current phenomena and mathematics.

Q. 419—What means is usually employed for starting synchronous motors?

A.—A small induction motor is mounted on the shaft or arranged to be belted to the synchronous motor shaft during the starting-up period. The induction motor is thrown in circuit first, and brings the armature of the synchronous machine to a speed slightly above synchronism; then the synchronous armature is connected to the mains and the induction motor is cut out. The field magnet of the synchronous motor is fully excited, of course, beforehand.

Q. 420—What is the relation between the speed of a synchronous motor and that of the generator supplying it with current when they have different numbers of poles?

A.—The speed of the motor is that at which it would have to run, if driven as a generator, to deliver the number of cycles which is given by the supply alternator. For example, a 12-pole alternator running at 600 revolutions per minute (10 per second) will deliver current at a frequency of 60 cycles a second; an 8-pole synchronous motor supplied from that circuit will run at 900 revolutions per minute, which is the speed at which it would have to be driven as a generator to give 60 cycles a second—the frequency of the 12-pole alternator.

Q. 421—Is there a simple formula giving the speed relations between generators and motors connected to the same circuit and having different numbers of poles?

A.—Yes; if P represents the number of poles of the generator

and S represents its speed; and if the poles and speed of the motor be represented by p and s, respectively, then

$$\frac{P \times S}{p} = s.$$

Q. 422—Is the difference between polyphase and single-phase synchronous motors the same as the difference between the generators?

A.—Of course; any alternator built to supply a certain kind of circuit will operate as a synchronous motor if its armature be

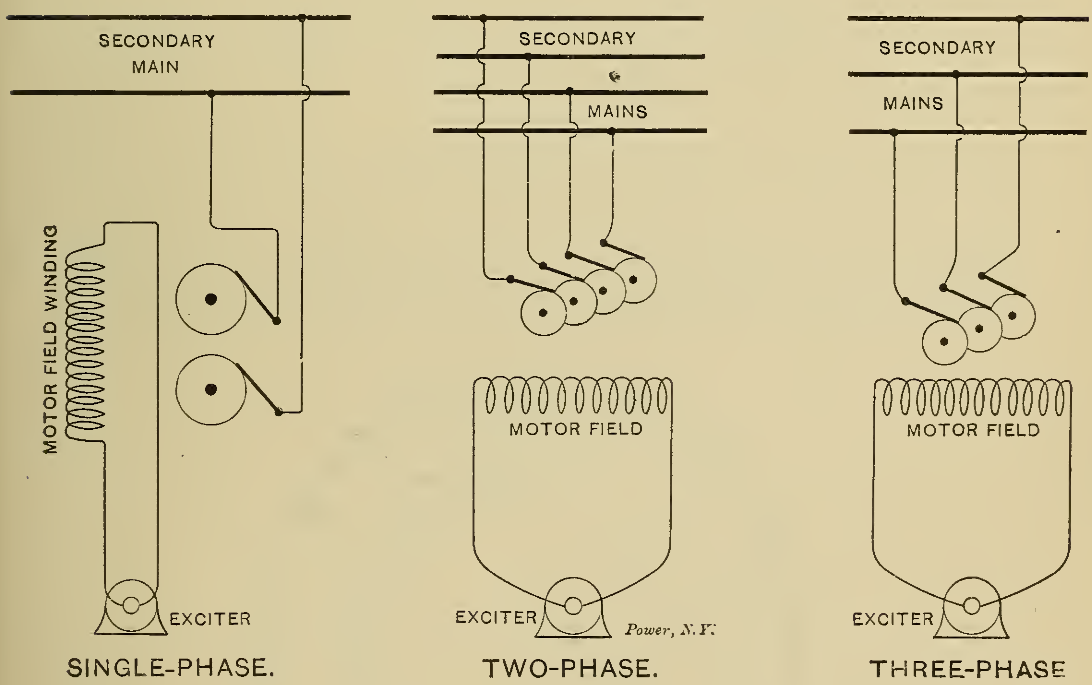


FIG. 209.

supplied with current from that kind of a circuit. Consequently a two-phase alternator is a two-phase synchronous motor, and so on throughout the list of different kinds of alternators.

Q. 423—Then the circuit connections of a synchronous motor must be the same as those of an alternator, are they not?

A.—Yes; Fig. 209 shows the connections. The circles represent the collector rings on the armature shaft.

Q. 424—What is the difference in construction between a synchronous motor and an induction motor?

A.—There is a great deal. The stationary part of an induction

motor is not at all like the field magnet of a synchronous motor, but is made up of thin disks shaped as shown by Fig. 210, just as an armature is made up. The revolving part, or rotor, is also radically different from an ordinary armature. It is made up of

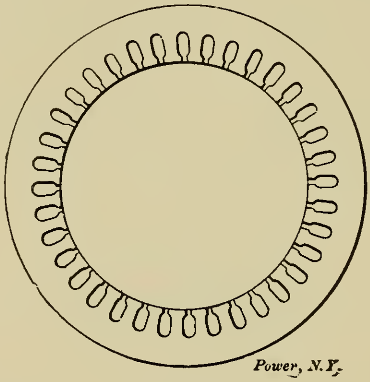


FIG. 210.

disks, like an armature core, but instead of slots for the winding, it has a series of holes around the edge, as shown by Fig. 211.

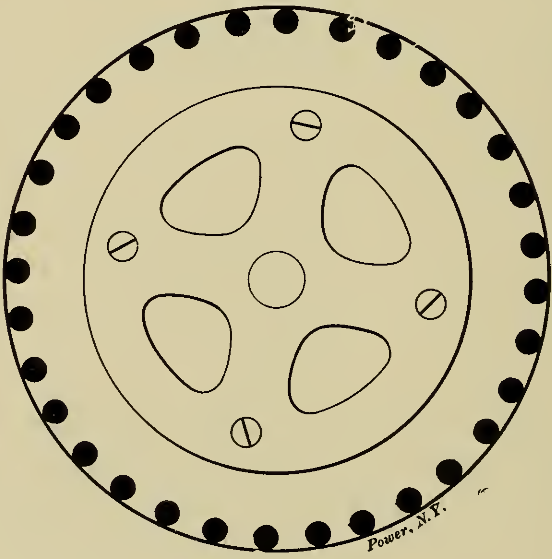


FIG. 211.

Q. 425—How are the field coils arranged?

A.—The field coils are disposed exactly like the armature coils of an alternator, so that each coil embraces several teeth, being divided into two or more sections, according to the number of

teeth per pole. Fig. 212 shows diagrammatically the winding for a pole of three teeth, for a single-phase motor field, or stator.

Q. 426—How are the field windings of a two-phase motor arranged?

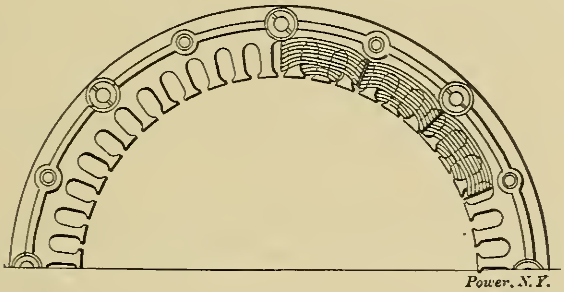


FIG. 212.

A.—The winding is divided into two groups, each wound to give the same number of poles, but interlinked, as shown by Fig. 213, so that the center of any pole of one group will be half-way between the centers of the adjoining poles of the other group. The current in one group of windings is at its maximum value

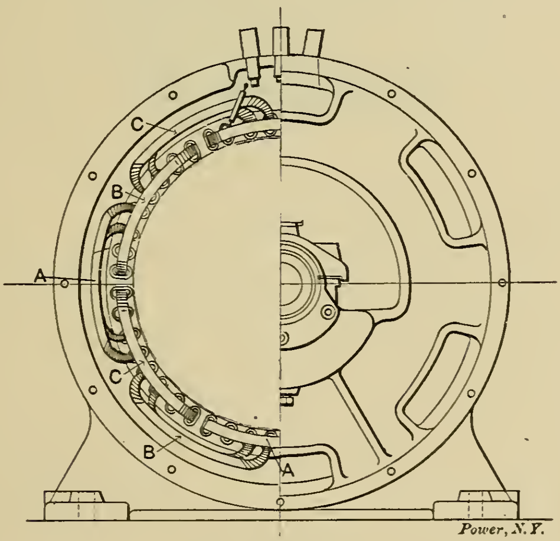


FIG. 213.

when the current in the other group is at zero, the two currents being supplied from a two-phase generator.

Q. 427—Then the poles are produced first by one set of windings and then by the other, are they not?

A.—Not exactly that; there are two sets of poles produced by

the two windings, and each set rises to its maximum strength at a different instant from the other. The resultant is what is known as a "rotary" field. The change of maximum polarity from one set of windings takes place in gradations, not in abrupt jumps, so that the effect in the air-gap is precisely the same as though a field magnet, excited by direct current, were revolving about the armature.

Q. 428—If the field revolves, why does the armature revolve also?

A.—The mechanical field structure does not revolve; it is only the magnetic field in the air-gap that rotates. This induces currents in the rotor, which make it revolve in an effort to keep up with the rotating field.

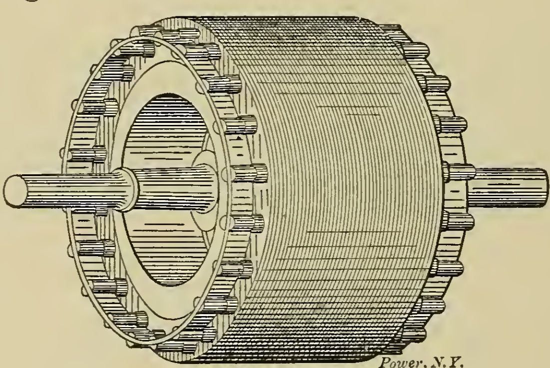


FIG. 214.

Q. 429—How is the rotor wound?

A.—In small machines it is not wound at all. The conductors are stout copper rods, threaded through the holes in the core and joined at both ends by a ring of copper, as shown by Fig. 214.

Q. 430—If the conductors are short-circuited, as the engraving shows them, why does the armature not burn out?

A.—Because the armature so nearly keeps up with the rotating field that the number of magnetic lines cut by the rotor conductors is very small, compared with the total number in the air-gap. The voltage induced in the rotor conductors is just sufficient to force enough current through the rods to pull the load.

Q. 431—What regulates the difference between the rotor speed and that of the rotating field?

A.—The load. If the rotor were driven at exactly the same

speed as the magnetic field, no current would flow in the rotor conductors, because they would travel with the flux instead of cutting it. Now, if it be left free for the flux to drag it around, it will lag behind the rotation of the flux, tending to stop, until the conductors cut sufficient lines of force to generate a voltage sufficient to force current through the conductors in large enough quantity to keep the rotor going.

Q. 432—But what determines just how much current is needed?

A.—The load. Work is measured in foot-pounds per minute. Now, if the motor is to do one-third of a horse-power (ignoring losses), this means 11,000 foot-pounds per minute; if the circumference of the rotor moves at the rate of 1,100 feet a minute, there must be a pull of 10 pounds on the conductors, exerted by the rotating flux. As explained under Q. 151-154, the pull in pounds between a conductor and a magnetic flux is given by the formula

$$\frac{\Phi C}{Kr} = \textit{Pull in pounds},$$

in which formula Φ represents the magnetic flux cut per revolution by the conductor; C is the current in the conductor, K, a constant and r, the radius of the rotor, in feet. As already explained, the more the rotor lags behind the magnetic field, the more lines of force are cut by the conductors; consequently, the more E.M.F. is induced in them and the more current is forced through them by this E.M.F. Therefore, the rotor speed will drop back until the number of magnetic lines cut by the conductors and the current passing through them are just sufficient to give the requisite pull; it cannot drop below this, because the pull keeps it up, but if there is the least increase in the load, requiring more pull, the speed will fall off a trifle until the balance in forces is restored.

Q. 433—The speed must be very unsteady, is it not?

A.—Not more so than in a good shunt-wound direct-current motor. It must be remembered that the pull increases just as fast as the speed changes, because an increase in magnetic lines also gives an increase in current. Thus, if the speed slacks off enough to double the number of magnetic lines cut per second, the pull will be doubled because the E.M.F. will have been doubled, causing the current to double also.

Q. 434—If the armature or rotor is not connected to the circuit the motor does not give any counter E.M.F., does it?

A.—Yes. The rotating field flux sweeps all of the wires around the inner edge of the stator ring, just as the flux from a rotating field magnet in a direct-current generator sweeps the wires on the stationary armature, and induces a counter E.M.F. in the field or stator windings. Fig. 215* is an end view—a sort of diagrammatic end view—of a two-phase four-pole induction motor, and Fig. 216 is an axial section of the same machine.

Q. 435—What is the difference between a two-phase motor and a three-phase motor?

A.—Simply the division of the field or stator coils into three

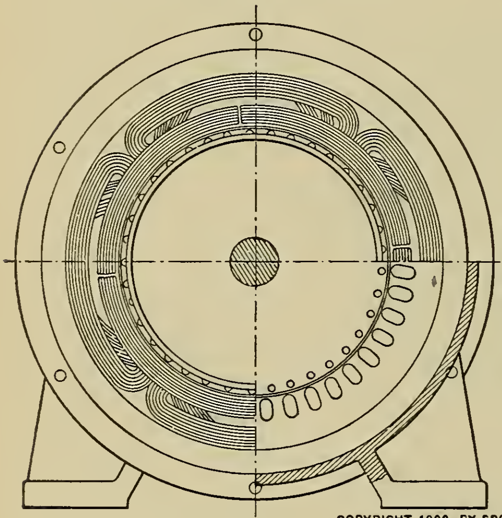


FIG. 215.

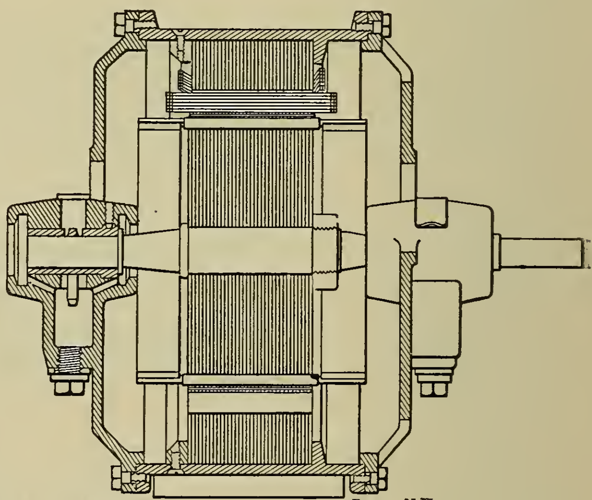


FIG. 216.

equal groups instead of two, the coils being put on in a manner corresponding precisely with the arrangement of three-phase alternator armature coils shown in a previous number. Fig. 217 shows a half view of a three-phase stator with the coils in place.

Q. 436—Does the field pass from one set of windings to the other, as in a two-phase motor?

A.—Yes; the rotation is more uniform, because each cycle is divided into three parts instead of two—that is to say, the rise and fall of the three separate fields is more gradually interlinked than when there are only two.

* From "Polyphase Electric Currents," by S. P. Thompson.

Q. 437—How is the speed of an induction motor calculated?

A.—The speed which it would take if the motor ran exactly with the rotating field is usually the one given. This is found

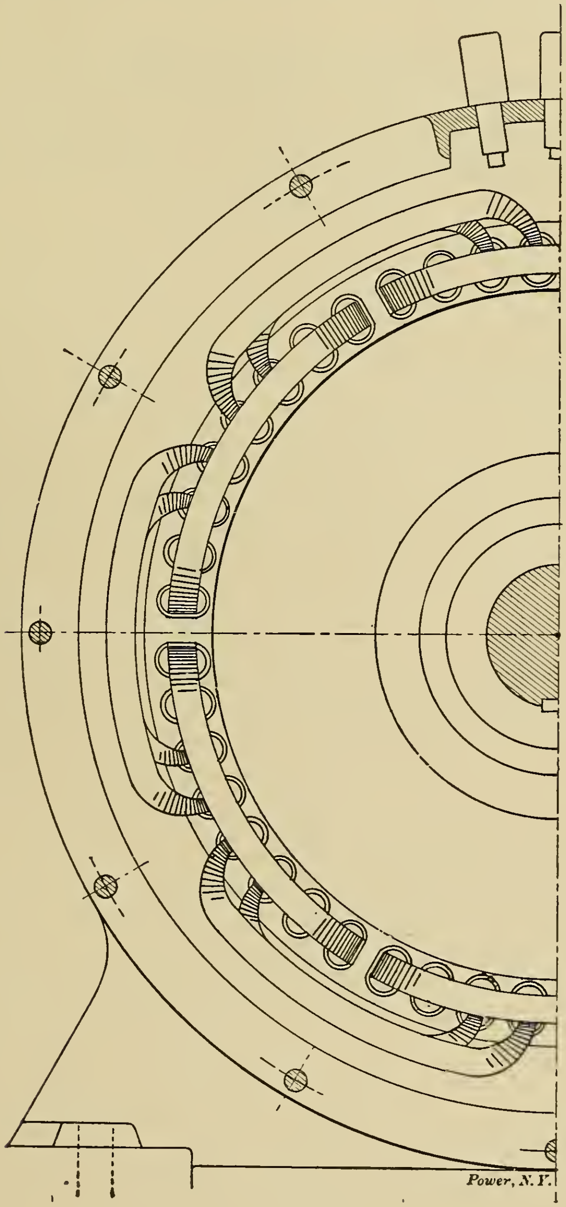


FIG. 217.

by dividing the frequency of the current supply by one-half the number of poles per phase. In formula shape:

$$\frac{2 \times \textit{Frequency}}{\textit{Poles}} = \textit{Revs. per second.}$$

It should be remembered that the term "poles," as applied to an induction motor, always means the number of poles per phase, or per winding. (Each winding is connected to a separate phase of the supply circuit.)

Q. 438—Then there are as many windings as there are phases?

A.—Always; and the field windings are divided up to form the same number of poles each, whether the machine is a two-phase or a three-phase motor.

CHAPTER XII.

THE ROTARY CONVERTER—REACTIVE REGULATORS.

Q. 439—What other alternating-current machinery is there in use?

A.—In the machinery class there is no more apparatus that can be considered as belonging strictly in the domain of alternating currents. Rotary converters are usually referred to as alternating-current apparatus because they are used in connection with alternating-current plants; they form the connecting link, however, between the two great classes of alternating and direct-current machinery.

Q. 440—What is a rotary converter?

A.—Broadly speaking, it is a direct-current dynamo (or motor) provided with collector rings and brushes in addition to the usual commutator and brushes.

Q. 441—What work does it do?

A.—It is used either to change alternating currents into a direct current or the reverse; usually it converts from alternating to direct current. Current is supplied to the armature through the collector rings, and the machine runs as a synchronous motor; the field magnet is excited from the brushes on the commutator which deliver direct current.

Q. 442—If the current that goes into the armature is alternating, how can it deliver direct current at the other brushes?

A.—The current is rectified by the passage of the armature wires under the field magnet poles, in a similar manner to the operation of a simple rectifying commutator. A reference to Q. 269 and 270 will show that if it were not for the commutator of a direct-current dynamo, it would deliver alternating current; in other words, the kind of current supplied by the armature of

an ordinary dynamo depends entirely upon the kind of apparatus employed for delivering the current to the outside circuit. If a commutator is used, we get direct current, but if collector rings are used, connected to opposite points of the winding of a bipolar armature, as in Fig. 218, and the field magnet is excited by direct current, we will get alternating current at the brushes. Now, the rotary converter is provided with both the collector rings and the commutator, so that it can deliver either direct current or alternating current, if it be driven by belt as a dynamo, or it may even deliver both at once. These machines are used in this way occasionally, in which case they are called double-current generators.

Q. 443.—Still it is not clear how the alternating current delivered to the collector rings of a rotary converter comes out as direct current at the commutator.

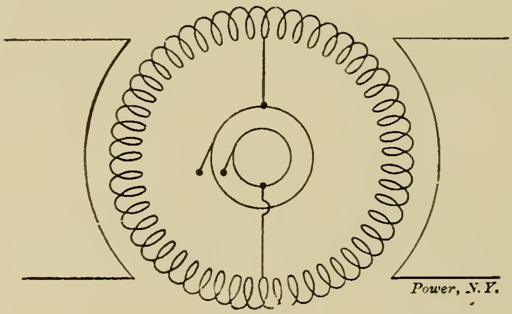


FIG. 218.

A.—The current generated in the armature when it is driven by a belt is alternating current while it is in the armature; it is changed to direct current by the commutator. Similarly, the alternating current fed to the winding through the collector rings traverses that winding precisely as though it were generated in it, and is changed to direct current by the commutator, with relation to the outside circuit to which it is delivered. It remains alternating current within the armature winding.

Q. 444.—And in passing through, it drives the armature as a motor?

A.—Precisely. And the operation is reversible; tne machine can be run as a motor on a direct-current circuit and alternating current may be taken off at the collector rings, exactly as from an alternator.

Q. 445.—Is a rotary converter multipolar?

A.—Always. Each of the collector rings is connected in actual practice to one-half as many points in the winding as there are poles, and the points must be precisely equidistant around the winding for each ring; in a single-phase converter there are two collector rings, and the points to which each is connected lie exactly half-way between the points to which the other ring is connected, as indicated in Fig. 219.

Q. 446.—How are two-phase and three-phase armatures connected to the collector rings?

A.—Each ring is connected to half as many points as there are magnet poles, and the points are at equal distances, as before; in

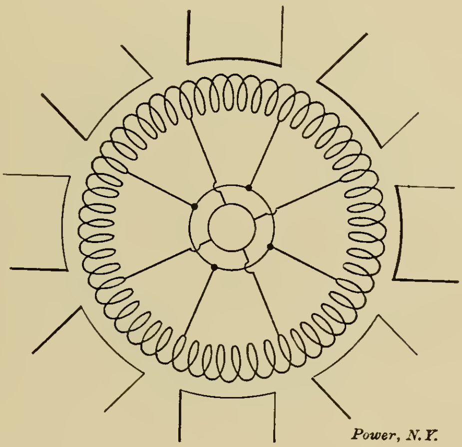


FIG. 219.

a two-phase machine there are four collector rings, and therefore four sets of taps or "points," and the four are equally spaced, exactly like the individual sets of taps. In a three-phase machine there are three rings and three sets of taps, the three sets being equally spaced with relation to each other, and the individual taps of each set being similarly placed with relation to each other. Fig. 220 is a diagram of the two-phase connections and Fig. 221 is a similar diagram of the three-phase arrangement, a four-pole field magnet being shown for sake of simplicity. These and Fig. 219 show the winding as a sort of Gramme ring, but it makes no difference whether it is a ring or a drum winding, so long as it is a symmetrical, closed-circuit arrangement of coils. In practice

the ordinary drum winding is used. In the diagrams the phases are indicated by the letters *A, B* and *C*.

Q. 447.—What determines the speed of a rotary converter?

A.—If it converts from alternating to direct, its speed is determined by the frequency of the alternating-current circuit, exactly like that of a synchronous motor. If it converts in the other direction, the speed is determined by the voltage of the direct-current circuit, like an ordinary direct-current motor.

Q. 448.—How is the machine regulated?

A.—When converting from alternating to direct current, the voltage of the direct-current output is regulated by varying the

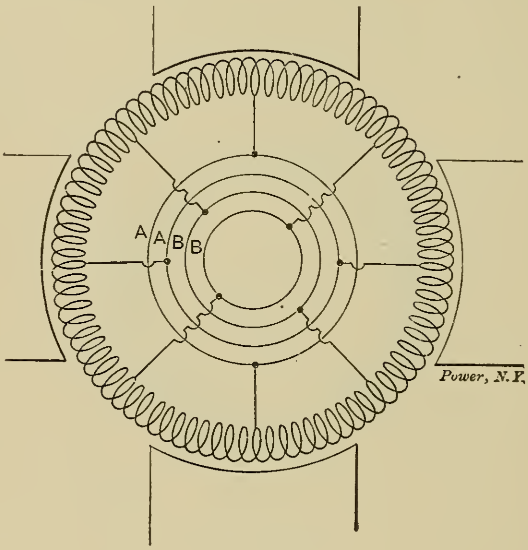


FIG. 220.

voltage of the alternating current supplied to the machine. This is usually done by means of an adjustable reactive coil in series with the supply circuits. When converting from direct to alternating current, the voltage of the delivered alternating current is regulated by means of adjustable reactive coils, in the same way as before.

Q. 449.—Why cannot the voltage be regulated by varying the strength of the field magnet?

A.—Because, as there is only one winding on the armature, there is an absolutely fixed ratio between the arithmetical average of the voltage of all the coils (direct current) and the geometrical average of the voltage of the coils between the taps. If the ma-

chine is delivering direct current, the voltage of that current is proportional to that of the alternating current supplied to the collector rings, regardless of the strength of the field; thus, a single-phase converter supplied with alternating current at 100 volts will deliver only 141.4 volts at the direct-current commutator; a two-phase machine will deliver the same voltage, and a three-phase machine will deliver direct current at 163.3 volts. Conversely, if it converts from direct to alternating, each 100 volts delivered to the commutator will cause a single-phase or two-phase machine to deliver 70.7 volts alternating, and a three-phase machine to deliver 61.23 volts alternating.

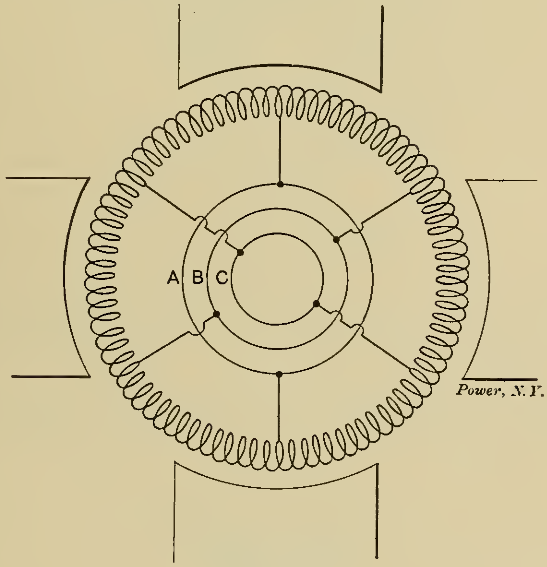


FIG. 221.

Q. 450.—What is the adjustable reactive coil mentioned above?

A.—It is a laminated core magnetized by a primary winding, like a transformer, and having secondary coils connected in series with the circuit between the transformer secondaries and the collector rings of the rotary converter; the effect of the coils is adjustable, so that the secondary E.M.F. may be varied to suit the requirements of the service. Fig. 222 is a diagram illustrating the general connections.

Q. 451.—How is the effect of the regulating coils adjusted?

A.—There are several ways. Fig. 223 shows the principle of a single inductive regulator. The fine-wire coil, *P*, is connected across the secondary circuit and magnetizes the laminated iron

core, *C;* an E.M.F. is thereby induced in the coarse-wire coil, *S,* which is in series with the circuit. The core is pivoted at its center so that it may be turned to the position shown in Fig. 224; in one position the E.M.F. induced by the secondary coil boosts the circuit, and in the other it opposes it.

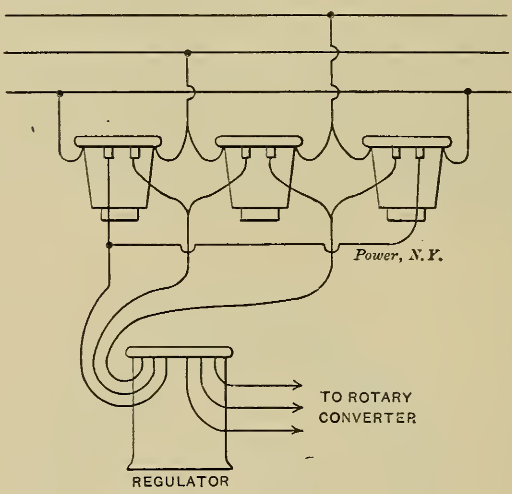


FIG. 222.

Q. 452.—Cannot the amount of boosting and opposition be graded?

A.—Certainly, when the core is parallel with the coil, *S,* the

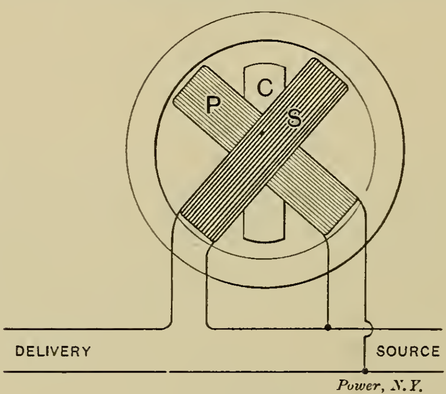


FIG. 223.

regulator neither boosts nor opposes; but a slight movement in the one direction results in a slight boosting, which increases very gradually until the core is midway between the coils, as in Fig. 223, for example. Conversely, a slight movement from the neutral position (within the coil *S*) in the opposite direction gives a small

opposing E.M.F., which increases until the core is midway between coils on the other side, as in Fig. 224, for example.

Q. 453.—Are there any other forms of induction regulator?

A.—Fig. 225 represents an arrangement that has been used to

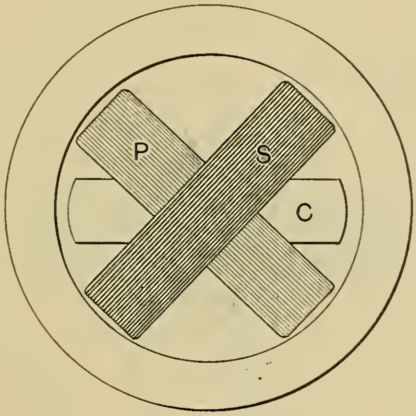
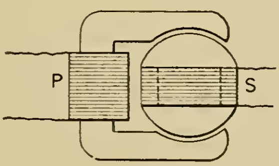


FIG. 224.

some extent. The principle is precisely the same—the boosting or lowering is regulated by varying the inductive relation between one of the windings and the rotatable core, *C*, and the adjustment gives a smooth gradation from maximum opposition to maximum boosting. With the core turned to the position shown in Fig. 226, the secondary winding has no E.M.F. induced in it.

Q. 454.—How do the two forms compare?

A.—There is not much choice between them. The one in Fig. 223 is less expensive in construction, and has the advantage that the windings are stationary. The one in Fig. 225 has also the



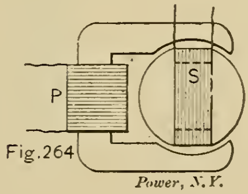


FIG. 225. FIG. 226.

disadvantage that the coarse-wire winding is the movable one, rendering heavy flexible connections necessary. Fig. 227 represents a regulator devised by the writer several years ago, in which this disadvantage is obviated and the coils of which are more

efficient inductively. This regulator, however, embodies the disadvantage of a moving high-potential coil and dangling high-potential connecting leads. In the position here shown, there is no E.M.F. induced in the secondary coil, *S*, but its reactance will

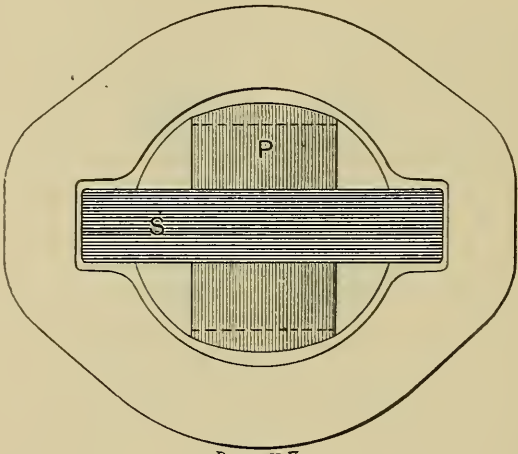


FIG. 227.

cut down the circuit E.M.F. slightly; the neutral position of the core, therefore, would be with the primary coil tilted somewhat to the right or left (according to the connections) of the position shown.

CHAPTER XIII.

ELECTRIC LIGHT.—THE ARC LAMP.

Q. 455—How is light produced by electricity?

A.—There are two methods in common use, and a third is in process of development. Those in use are the vaporization and combustion of carbon, in the electric arc, and bringing a fine car-

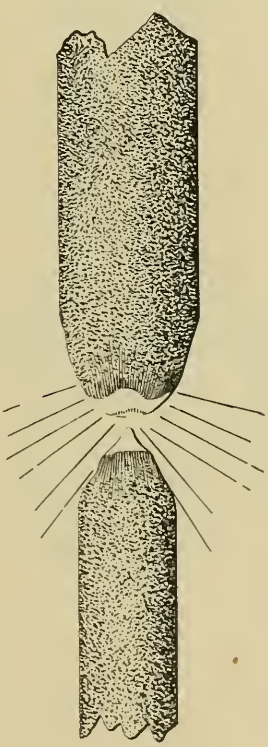


FIG. 228.

bon thread to a white heat, in the incandescent lamp. Fig. 228 shows the appearance of an electric arc produced by direct current.

Q. 456—How does the vaporization of carbon produce light?

A.—It does not, directly; the ends of two sticks of carbon are brought together and a current is passed through them; then

they are separated and the current continues to flow across the gap between them by virtue of a so-called "stream" of carbon vapor, which serves as a conductor between the two points, and also as a fuel for combustion to enhance the light.

Q. 457—What causes the carbon vapor stream?

A.—The first passage of current from carbon to carbon heats the carbon tips and volatilizes them.

Q. 458—Can an arc be maintained between metal tips?

A.—Not with ordinary voltages, and a steady arc cannot be so maintained in open air at any voltage.

Q. 459—What voltage is required for an arc between carbon points?

A.—If the arc is operated in the open air, from 42 to 55 volts are required at the gap between the carbons with direct current and 28 to 35 volts with alternating current, according to the length of the arc and amount of current passing.

Q. 460—Why is less voltage required with alternating current?

A.—Because a steady arc cannot be maintained across so long a gap as with direct current, and the shorter gap requires less E.M.F. to force the current across.

Q. 461—What causes the difference in steadiness?

A.—With direct current there is an electrolytic wasting away in the center of the positive carbon, forming a hollow or crater in the end; this crater steadies the arc. With alternating current no crater is formed, because both carbons are alternately positive and negative, preventing any electrolytic action. Both carbons burn to a point, and the arc becomes unsteady and flickering at a shorter length than when steadied by the direct-current crater.

Q. 462—Is an arc operated otherwise than in open air?

A.—Yes; the most modern form of lamp is provided with a glass envelope or inner globe immediately surrounding the arc, as shown by Fig. 229.

Q. 463—What is the object of enclosing the arc?

A.—To prolong the life of the carbons, and also to obtain a more diffused light.

Q. 464—How is the life of the carbons prolonged?

A.—The supply of oxygen is greatly restricted, and the rate of consumption is therefore slower. The envelope cannot fit abso-

lutely air tight, so that there is still a small amount of oxygen supplied to the arc.

Q. 465—What is the life of the carbons of an open arc?

A.—The life varies with the hardness and size of the carbons and the amount of current. With average carbons, $\frac{1}{2}$ inch in diameter, and a current of 9.6 amperes, the rate of consumption is approximately $1\frac{1}{2}$ inches an hour for the positive carbon, and a

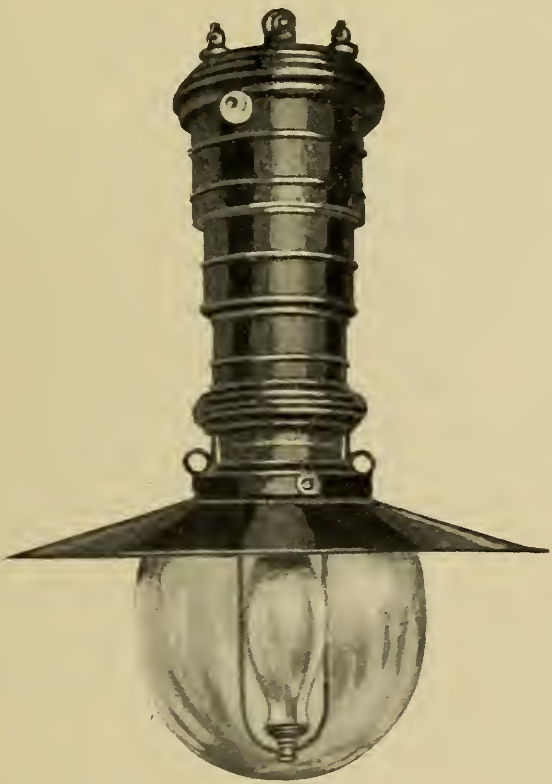


FIG. 229.

trifle over half that rate for the negative carbon, with direct current.

Q. 466—Why does the positive carbon burn twice as fast as the negative carbon?

A.—Partly because the current in passing from the positive and to the negative carbon deposits on the negative tip some particles of carbon, due to disintegration of the positive tip. Moreover, in addition to the consumption of the outer part of the positive tip in the ordinary manner by oxidation, the center wastes

away electrolytically, as previously stated, whereas the negative carbon is consumed by oxidation alone.

Q. 467—What voltage is required for an arc enclosed as in Fig. 229?

A.—From 65 to 80 volts, according to the distance apart of the carbons and character of the current.

Q. 468—Cannot an enclosed arc be operated at the same voltage as an open arc?

A.—Not satisfactorily. The rate of combustion (oxidation) is so slow that a short arc would not give sufficient illumination.

Q. 469—What is the life of the carbons of an enclosed arc?

A.—A first-class grade of carbon under average conditions will be consumed at a rate slightly less than $\frac{1}{10}$ inch per hour for the positive and somewhat more than one-half of this for the negative, in a direct-current lamp.

Q. 470—Is there any difference between the action of the carbons on a direct-current circuit and on an alternating-current circuit?

A.—A decided difference. With alternating current both carbons burn alike from oxidation only, no electrolytic wasting occurring. The upper carbon burns a trifle more rapidly than the lower because of the ascent of heat from the arc. Furthermore, there being no electrolytic waste, there is no hollow or crater formed in the center of the upper carbon, as in a direct-current lamp; both carbons burn to a point, being consumed from the outside by oxidation, as stated under Q. 461.

Q. 471—What is the shape of the carbon?

A.—It is made up into round pencils or rods, from $\frac{3}{8}$ inch to $\frac{3}{4}$ inch in diameter, and from 7 to 12 inches in length; the arc is formed between the ends of two carbons, as indicated in Fig. 228.

Q. 472—What happens when the ends burn away?

A.—One of the carbons is automatically moved toward the other by minute degrees as the carbon wastes away, so that the length of the arc is kept practically constant. This operation is termed "feeding."

Q. 473—How is the carbon fed?

A.—By some one of several forms of mechanism controlled by the current. Fig. 230 illustrates the principle on which many lamps are constructed. The carbons are mounted vertically, the

lower one being held in a stationary clamp and the upper one in a clamp at the end of a sliding brass rod, *r*. This rod is raised by a clutch, represented conventionally by the washer *c*. The action is as follows: The upper carbon rests on the lower one when the lamp is idle; when current is turned on, it passes through a coarse wire solenoid, *S*, the finger or brush, *b*, and both carbons. Practically no current passes through the fine wire

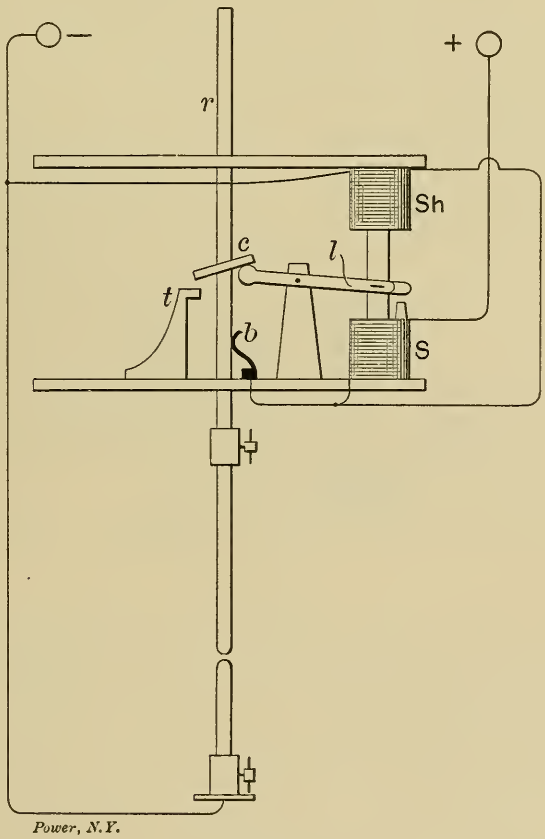


FIG. 230.

solenoid, *Sh*, as it is short-circuited by the carbons. The solenoid, *S*, lifts the carbon-carrying rod, *r*, through the lever, *l*, and the clutch, *c*, and "strikes" the arc. As soon as the carbons are separated, current is shunted through the coil, *Sh*, and as the carbons burn away, more and more current passes through this coil until it overcomes the pull of the lower solenoid and lowers the clutch against the tripping lug, *t*, relieving the grip of the clutch and allowing the rod to feed downward.

Q. 474—Does the carbon feed down into contact with the lower one again?

A.—No; the instant the rod begins to feed, the shortening of the arc reduces the current in the shunt solenoid, *Sh,* and the lower solenoid immediately renews the grip of the clutch on the rod.

Q. 475—Then the arc lengthens and shortens?

A.—It does to an imperceptible extent; the variations are extremely small. For example, when the arc is at normal length, say 100 mils,* the relations are such that the two solenoids are so nearly of equal strength that the weight of the carbon and rod is just supported by the lower solenoid. Now, when the upper carbon burns away, say 2 per cent (2 mils), the resistance of the arc will increase 2 per cent, the voltage between the carbons (and consequently at the terminals of the shunt solenoid) will increase 2 per cent, and the current in the shunt solenoid will accordingly increase 2 per cent. This is usually enough to overcome the friction of the mechanism and allow the clutch to loosen its grip on the rod. As soon as the arc is restored to its proper length the state of magnetic equilibrium is restored, and the shunt solenoid restrains the rod from further movement.

Q. 476—Why does the voltage at the arc increase when the arc lengthens?

A.—Lamps of the kind described are operated in series on constant-current circuits, and in order to maintain the current constant the voltage must be varied at the dynamo as the resistance of the circuit varies.

Q. 477—Are any other forms of arc lamp mechanism used on constant-current circuits?

A.—There are several modifications of the clutch type of mechanism, and also a clock-work form in which gearing meshed with a rack on the rod is employed to control the movement of the rod. Fig. 231 illustrates the principle of the clock-work lamp; here the lower solenoid is in shunt to the arc and the upper one in series, the lever being pivoted at the end instead of in the middle as in Fig. 230.

Q. 478—Are two solenoids always necessary?

* A mil is 1-1000 inch.

A.—No. In many lamps built to operate on constant-potential circuits only a single solenoid, in shunt to the arc, is used; its function is to "feed" the carbon.

Q. 479—What lifts the carbon to form the arc?

A.—The carbons are normally held apart by a spring, and the shunt solenoid opposes the spring, tending to draw the mechanism downward, as indicated in Fig. 232. When the lamp is connected to the circuit, no current passes through the carbons; as the supply circuit is at constant potential, a strong current will pass through the shunt coil, pulling down the lever and allowing the upper carbon to drop. As soon as it touches the lower carbon, the shunt coil is short-circuited and allows the spring to raise the clutch and carbon, striking the arc. Thereafter, the spring fulfils the function of the series solenoid in the double solenoid lamp.

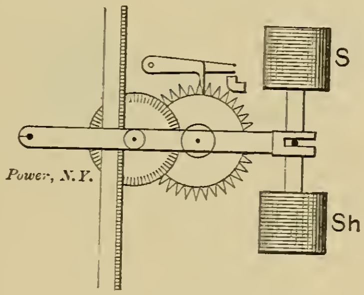


FIG. 231.

Q. 480—When the carbons separate, removing the short circuit from the solenoid, does not the line current cause it to pull the lever down again, producing a see-saw movement?

A.—No. When the carbons separate to the normal arc length, 5 amperes or more flow through them and the resistance coil, and the drop in the resistance coil reduces the voltage at the arc below the voltage of the circuit, so that the current in the shunt coil is less after the arc is established than before.

Q. 481—If the circuit is at constant potential, does not the voltage of the shunt solenoid terminals remain constant after the arc is struck?

A.—No; as the carbons burn away the lengthened arc reduces the current through the carbons and the resistance coil. This reduces the drop in the resistance coil, leaving more of the circuit potential active at the shunt coil terminals. Thus, if the circuit

E.M.F. were 55 volts, the resistance coil were of 4 ohms and the main current at normal arc were 6 amperes, the drop in voltage in the resistance coil would be $6 \times 4 = 24$ volts, leaving 31 volts at the arc and the shunt coil terminals. Now, when the carbon burns away enough to reduce the current to, say, 5.9 amperes, the drop in the resistance coil will be $5.9 \times 4 = 23.6$ volts, leaving 31.4 volts at the arc and the shunt coil terminals; the current

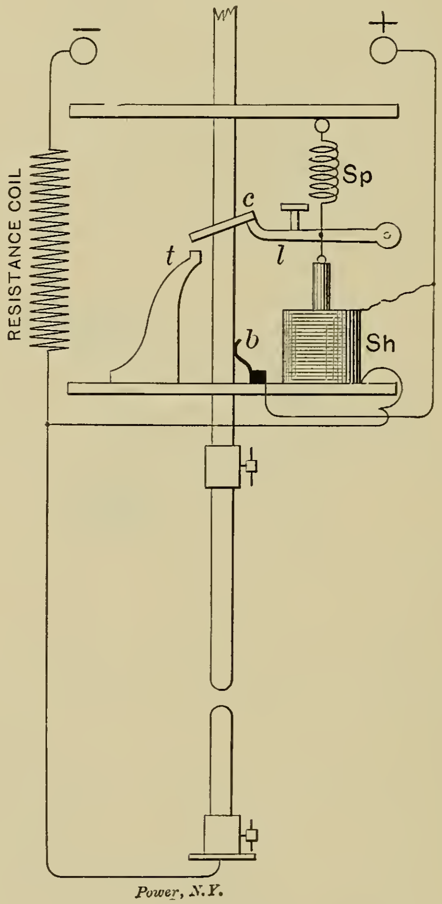


FIG. 232.

in the shunt coil will then be $\frac{31.4}{31} = 1.013$ times its former strength. An increase of from 2 per cent to 5 per cent is required to overcome the friction of the mechanism and cause feeding.

Q. 482—What happens when the carbons are all burned out?

A.—If the lamp is operated singly on a constant-potential cir-

cuit, the rod comes to a stop at the end of its travel, and the arc grows longer and longer until it breaks. In a lamp operated in series with other lamps, the entire lamp mechanism is short-circuited by an automatic cut-out within the lamp box.

Q. 483—What is the automatic cut-out like?

A.—There are several forms, depending on the type of lamp and individual ideas of the makers. Almost all series arc lamps contain a contact finger mounted on the carbon-rod and arranged to connect the two binding-posts of the lamp when the carbon-rod reaches its lowest position. Such an arrangement is indicated in

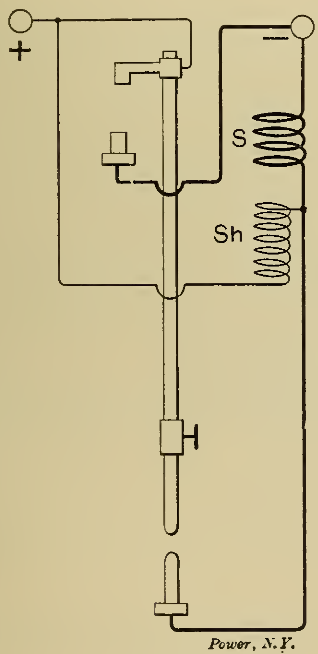


FIG. 233.

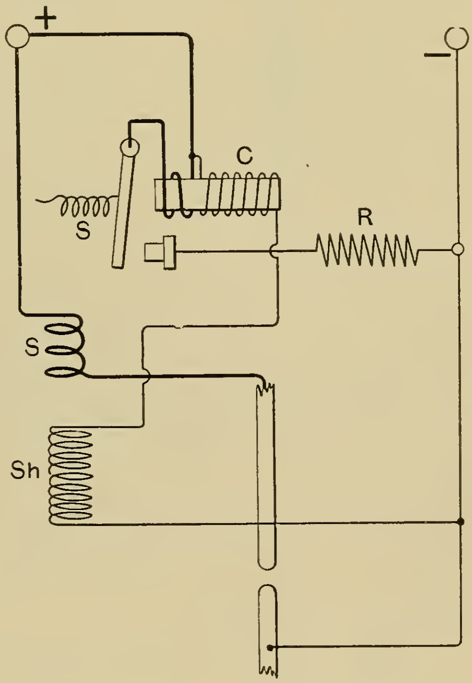


FIG. 234.

Fig. 233; the series solenoid is in this case connected between the bottom carbon and the negative post.

Q. 484—What other forms are commonly used?

A.—There is always some form of emergency cut-out which operates in case the mechanism becomes disabled during the life of the carbons and also when they have burned out. Fig. 234 represents an electromagnetic cut-out, the essentials of which form the basis of almost all emergency cut-outs. The magnet, *C*, has two windings, one of fine wire connected in shunt to the arc, and the other of coarse wire, normally open. As long as the arc

is normal in length, the spring, *s*, is stronger than the magnetism due to the fine wire coil. If the arc becomes abnormally long, the voltage at the terminals of the cut-out coil rises and the resultant increase in current in the coil overcomes the spring and pulls the armature against the contact. This gives the line current a short path from one post to the other, through the coarse wire on the magnet, and a resistance coil, *R*, cutting out the lamp.

Q. 485—Why is the coarse-wire winding used?

A.—Because the armature would not stay closed without it, the shunt coil being short-circuited along with the other parts of the lamp.

Q. 486—What is the object in using the resistance coil, *R?*

A.—To maintain an appreciable difference of potential at the terminal binding-posts of the lamp so that in a case where the cut-out operates on account of a "hang-up" of the mechanism, if the trouble should disappear and the carbons come together there will be sufficient current shunted through the carbons and series solenoid, *S*, to weaken the series winding of the cut-out magnet and open the cut-out, permitting the lamp to resume operation.

Q. 487—Why should the mechanism hang up?

A.—There are many accidental derangements, any one of which might cause the mechanism to stick. If the carbon-carrying rod of a clutch lamp is not properly cleaned it may stick in the clutch; the same is true of a rod slightly bent and of one that has been dented. A sharp jar might suffice to free the rod and the lamp would start up again.

Q. 488—Are arc lamps much used on alternating-current circuits?

A.—Yes, to a great extent. All alternating-current lamps are of the enclosed-arc type.

Q. 489—Are they exactly like enclosed-arc direct-current lamps?

A.—In general principle, yes; in constructional details they are different. The chief difference lies in the solenoid core, which is laminated in order to prevent "eddy" currents.

Q. 490—How can a round rod be laminated?

A.—The core is not a rod in such a case and not always round; it is made of either a strip of thin iron rolled into the shape indicated by Fig. 235 or a bundle of very small iron wires, as in Fig.

236, or else a bundle of flat iron strips, as in Fig. 237. The last two are the commonest forms.

Q. 491—Are alternating-current lamps operated in series?

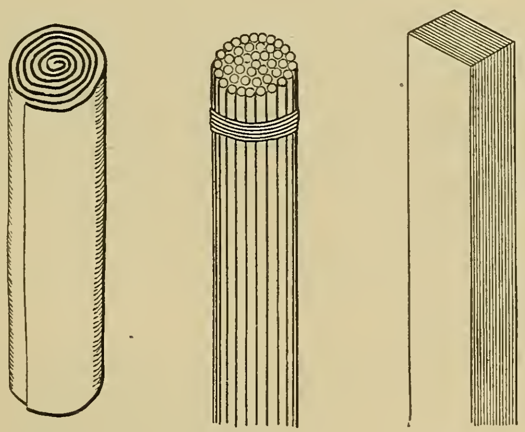


FIG. 235. FIG. 236. FIG. 237.

A.—Usually, although there are many lamps operated singly on constant-potential circuits of 100 to 110 volts. The lamps that work in series are also supplied from some constant-potential source but of high E.M.F., the current through the lamps being maintained constant by some auxiliary means.

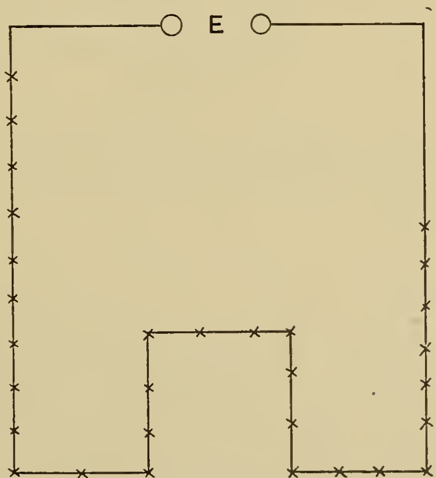


FIG. 238.

Q. 492—If the E.M.F is constant how can the current be kept constant?

A.—One of the commonest methods is to insert more or less

reactance in the circuit, so that the total E.M.F. required is always the same. For example, in Fig. 238, where each cross mark represent a lamp, if each lamp requires 65 volts and 6.6 amperes and the drop in the circuit wiring is 50 volts, the E.M.F. required at the source, *E*, would be $30 \times 65 + 50 = 2{,}000$ volts. Now if two lamps be cut out and a reactance of 19.7 ohms be inserted, as indicated in Fig. 239, the E.M.F. required by the lamps and wire will be reduced to $28 \times 65 + 50 = 1{,}870$ volts; but the drop at the reactance will be $19.7 \times 6.6 = 130$ volts, so that the total E.M.F. required at *E* will remain 2,000.

Q. 493—Then the reactance must be adjusted every time a lamp is cut in or out?

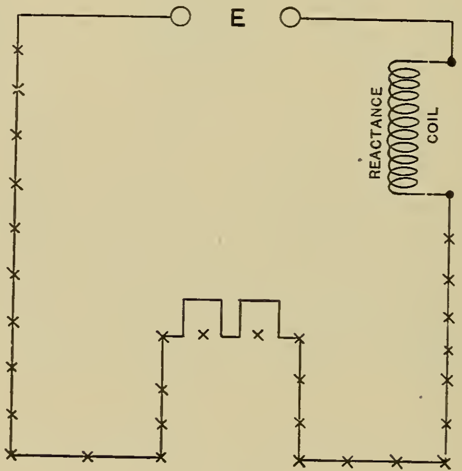


FIG. 239.

A.—Yes; but this is done automatically. A regulator is used which varies the reactance as the circuit requires it, without any attention whatever.

Q. 494—How is the regulator constructed?

A.—Fig. 240 illustrates the arrangement of one of these instruments. Two solenoids, *M M*, are hung from an insulating slab and a U-shaped core, *C*, is suspended from one arm of a lever, *L*, with the ends of its legs inserted a little way into the coils, as shown. The core is partly counterbalanced by weights, *W*. So long as the line current remains normal, with the full number of lamps in circuit, the ends of the core legs remain near the ends of the coils, the weights being adjusted to balance the core and the magnetic pull of the coils under those conditions. Now if one or

more lamps be cut out, lowering the resistance of the circuit, the current will increase, and the solenoids being strengthened, they will draw the core upward. As it enters the coils, the core increased their self-induction and consequently their reactance, and the increase in reactance reduces the current. When the core has been drawn up to such a point that the current has decreased to normal, the pull of the solenoids is exactly balanced by that part of the core weight not counterbalanced by the weights, and no

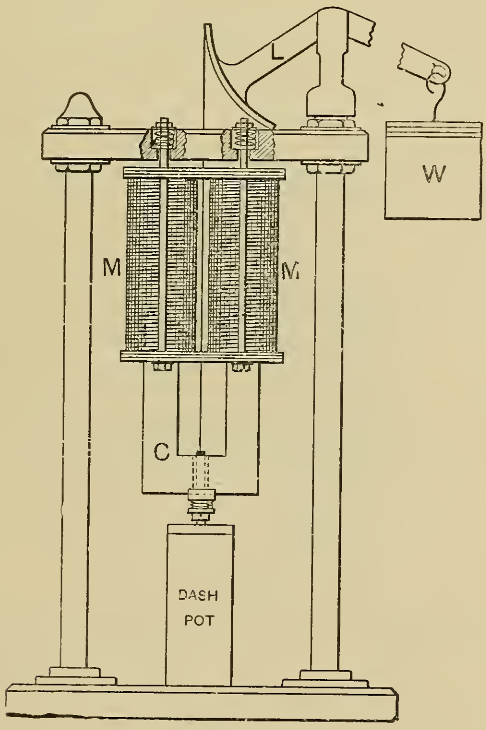


FIG. 240.

further movement occurs. Cutting out more lamps causes a further movement upward, while cutting in lamps weakens the line current and the core drops until equilibrium is restored. A dashpot below the core steadies its motion and prevents see-sawing when there happen to be several changes in the line in rapid succession.

Q. 495—Is not the pull of the solenoid greater when the core is far in than when it is at the mouth?

A.—Yes; with the core half way up the solenoid, the same

amount of current will exert a stronger pull than when it is at the bottom.

Q. 496—Then will not the core require less current to balance it the higher it goes?

A.—It would except for the shape of the lever arm to which the counterweights are hung. As the core goes up and the weights go down their effective pull decreases, owing to the constantly decreasing "leverage," so that the solenoid has to hold up a greater and greater proportion of the weight of the core. The

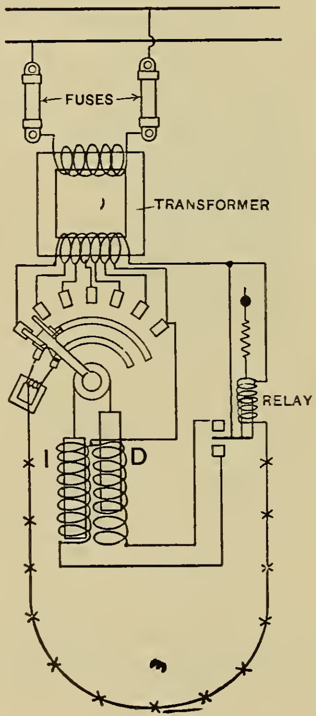


FIG. 241.

angle of the weight arm is such that the decrease in effective counterbalancing as the weights go down corresponds precisely to the increase in the pull of the solenoids at normal current.

Q. 497—Why cannot the circuit E.M.F. be adjusted, as in the case of a direct-current arc circuit?

A.—It can be, and this method is extensively used. Fig. 241 represents one form of automatic potential regulator. The transformer that supplies current to the arc circuit has taps led out from the secondary winding by means of which any proportion

of the total winding may be connected to the circuit. Two solenoids, *I* and *D*, actuate a pivoted arm which cuts in and out sections of the winding just like a rheostat arm cuts in and out resistance wire. A relay in the lamp circuit sends current through one or the other of the solenoids, according to the requirements of the circuit. The solenoid *I* increases the impressed E.M.F. by cutting in sections of the transformer secondary, and *D* works in the opposite direction.

Q. 498—Are there any other methods of regulating series alternating current circuits?

A.—One other method is in general use. This consists of using a transformer which takes current at constant potential in its

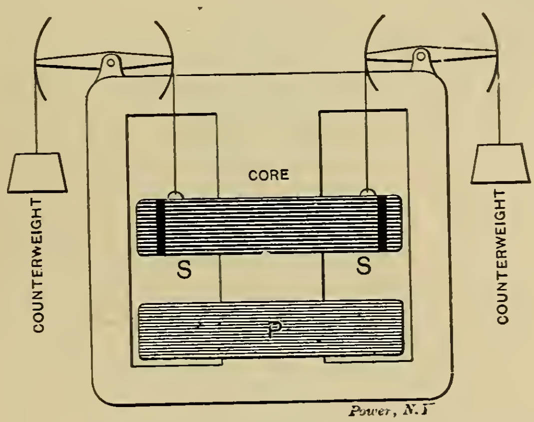


FIG. 242.

primary winding, and delivers constant current at varying E.M.F. at the secondary terminals.

Q. 499—How does this transformer differ from the ordinary kind?

A.—It is provided with movable secondary coils that are shifted bodily away from or toward the primary winding, according as the secondary E.M.F. needs to be decreased or increased in order to maintain constant current.

Q. 500—What shifts the coils?

A.—The mutual magnetic repulsion between the primary and secondary windings. Fig. 242 shows the principle of construction. The primary coil, *P*, is stationary, and the secondary coil, *S*, is hung from levers carrying weights that partly counterbalance it. As long as the current remains normal, the force of repulsion

between the coils equals the uncounterbalanced part of the coil's weight. Any increase in secondary current increases the repulsion, and the coil is lifted away from the primary coil until the E.M.F. induced in it by the primary has decreased enough to bring the secondary current down to normal value.

Q. 501—Why does the distance between the coils affect the secondary E.M.F.?

A.—The greater the distance the less primary magnetic flux will be cut by the secondary wires.

Q. 502—What becomes of the flux that is not cut?

A.—It leaks around the outside of the primary coil, between the two windings.

Q. 503—Why do the two coils repel each other?

A.—Because the current in the secondary is always opposite in direction to that in the primary, so that at any given instant the flux due to the secondary coil is opposed to that created by the primary coil.

CHAPTER XIV.

THE INCANDESCENT LAMP.

Q. 504—What is the construction of the incandescent lamp?

A.—A fine thread of carbon, known as a "filament," is bent into one or more loops or spirals and cemented at the ends to two pieces of platinum wire; the whole is enclosed in a glass bulb,

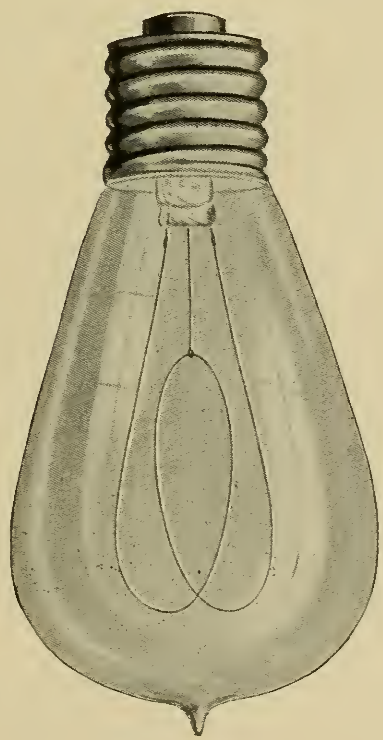


FIG. 243.

from which practically all of the air has been exhausted, the platinum wires projecting through the wall of the bulb and connecting with the outside lamp terminals. Fig. 243 shows a modern incandescent lamp.

Q. 505—Why does this filament give light?

A.—The passage of current through it raises its temperature to white heat.

Q. 506—How much current is required?

A.—That depends on the thickness and character of the filament. The current ranges from 1-6 ampere in lamps of high voltage and small power to 10 amperes in lamps of low voltage and large size.

Q. 507—Why is platinum wire used to connect the filament with the lamp terminals?

A.—Because its coefficient of expansion is so near that of the glass that expansion and contraction do not affect the seal where the wires go through. This is not true of any other metal.

Q. 508—Why is the air exhausted from the bulb?

A.—In order to prevent the immediate destruction of the filament by combustion. A lamp filament heated even to a red glow in air will be promptly consumed.

Q. 509—Does the filament last indefinitely in a vacuum?

A.—No. The useful life ranges from 400 to about 1,000 hours, according to the efficiency of the lamp.

Q. 510—What is meant by the efficiency?

A.—The candle power given out* per watt of power delivered to the lamp. Thus, a 16-c. p. lamp, taking 64 watts, and known as a "4-watt" lamp (4 watts per candle), has an efficiency of $\frac{1}{4}$ candle per watt.

Q. 511—How does the efficiency affect the life?

A.—The higher the efficiency the smaller the filament and the greater the current density in the filament. The higher, therefore, will be the temperature, and, consequently, the more rapid the deterioration of the filament.

Q. 512—What is the ordinary temperature of a filament?

A.—According to Prof. H. J. Weber, 2895.8° Fah. for a 3.1-watt filament and 2840° Fah. for a 4-watt filament.

Q. 513—Why does the filament deteriorate if there is no combustion?

A.—Because of a sort of wasting away, due to what appears to be the vaporization of very minute particles of carbon from the surface of the filament, which are deposited on the wall of the bulb. This wasting or "evaporation" is uneven, the filament be-

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* The mean horizontal candle-power, measured with the lamp revolving at 180 r. p. m.

comes thinner at some one point than elsewhere, and this point gives way.

Q. 514—Does not this wasting affect the light before the filament breaks?

A.—Very materially. The reduction in the size of the filament reduces its radiating surface, and also increases its resistance so that less current passes and less light is produced. Moreover, the deposit of carbon on the interior of the bulb reduces more and more the passage of light rays as the deposit increases. The re-

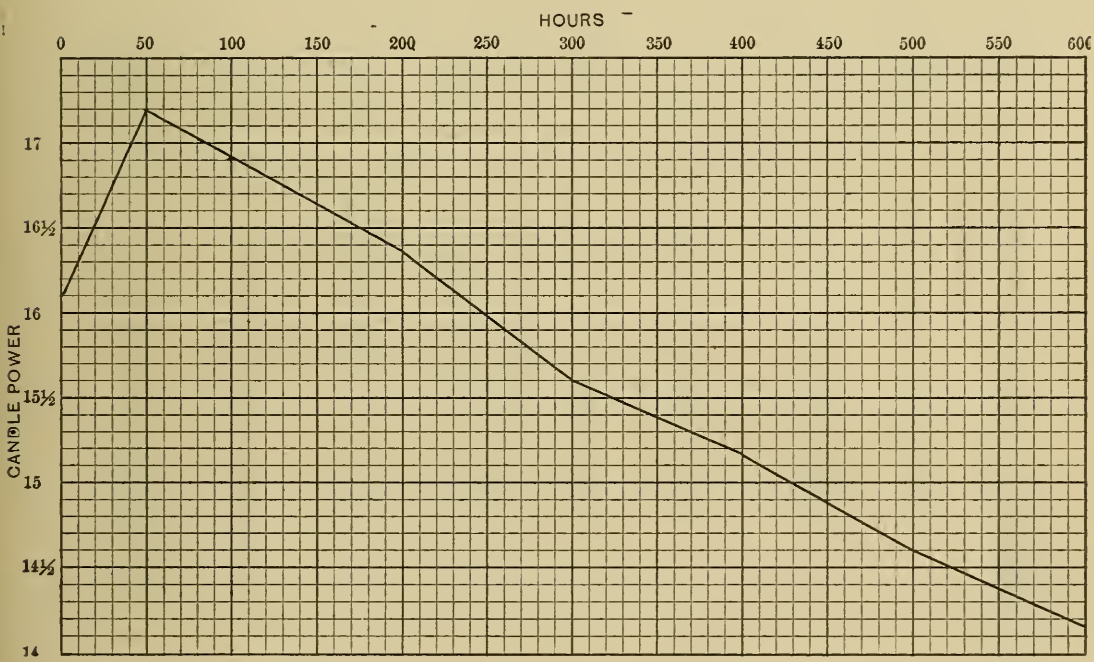

FIG. 244.

duction of candle-power due to these two causes usually reaches a point, before the filament breaks, where it is more economical to buy a new lamp than to continue using the old one.

Q. 515—How rapidly does the ordinary lamp deteriorate?

A.—This is easiest shown by a diagram, such as Fig. 244, where the "curve" across the regular rulings indicates the candle-power of a well-known 3.1-watt, 16-c. p. lamp at different points during its life. Starting at 16.1 candle-pawer, the brilliancy increases abruptly to 17.2 candle-power and then gradually falls, until after 600 hours it has dropped to 14.15 candles.

Q. 516—What are the standard efficiencies?

A.—Lamps for 110 volts are made to give a candle power with 3.1, $3\frac{1}{2}$ and 4 watts; lamps for 50 volts and under have been made to take as low as 2.8 watts per candle; while 220-volt lamps usually take from 4 to $4\frac{1}{2}$ watts per candle.

Q. 517—What is the resistance of a filament?

A.—The resistance of a $3\frac{1}{2}$-watt, 16-c. p. lamp for 112 volts is precisely $\frac{1}{2}$ ohm, hot; when cold the resistance is about 1 ohm.

	STANDARD 3.1 WATT LAMP.				STANDARD 3.5 WATT LAMP.			
Voltage Per Cent of Normal.	Candle-power Per Cent of Normal.	Watts per Candle-power.	Life Per Cent of Normal.	Deterioration Per Cent of Normal.	Candle-power Per Cent of Normal.	Watts per Candle-power.	Life Per Cent of Normal.	Deterioration Per Cent of Normal.
90	54	4.63	941	11	53	5.36	---	---
91	38	4.41	716	14	56	5.09	---	---
92	52	4.21	555	18	61	4.85	---	---
93	66	4.04	435	23	65	4.63	---	---
94	70.5	3.89	345	29	69	4.44	394	25
95	75	3.74	275	36	73	4.26	310	32
96	80	3.59	220	45	78	4.09	247	44
97	85	3.46	179	56	83	3.93	195	51
98	90	3.33	146	69	88	3.78	153	65
99	95	3.21	121	83	94	3.64	126	79
100	100	3.10	100	100	100	3.5	100	100
101	106	3.00	82	122	106	3.38	84	118
102	112	2.91	68	147	111	3.27	68	146
103	118	2.82	56	179	116	3.16	58	173
104	124	2.73	46	217	123	3.05	47	211
105	130	2.64	38	263	129	2.95	39	253
106	137	2.56	32	313	137	2.85	31	316
107	---	---	---	---	143	2.76	26	380
108	---	---	---	---	152	2.68	21	474
109	---	---	---	---	159	2.60	17	575
110	---	---	---	---	167	2.53	16	637

The resistance decreases rapidly as the temperature rises, and does not vary appreciably after the filament has passed red heat.

Q. 518—What effect is produced by using a lamp on a circuit of different voltage from the voltage it was intended for?

A.—If the voltage is too low the candle-power is reduced, the efficiency reduced and the life is prolonged because the temperature is below normal. If the voltage is too high, the opposite effects result. The accompanying table shows the results of varying the voltage on 3.1-watt General Electric lamps.

CHAPTER XV.

THE NERNST LAMP.

Q. 519—What is the third method of electric lighting mentioned under Q. 755?

A.—The heating of a poor conductor to incandescence, somewhat similarly to the manner of operating incandescent lamps.

Q. 520—What is the difference between the two methods?

A.—In the incandescent lamp the white-hot conductor is operated in a vacuum, as described. In the other lamp the illuminating conductor is enclosed in a globe, but the air is not exhausted; in fact, a little air is desirable, as in the case of the enclosed arc.

Q. 521—What is the conductor made of?

A.—Refractory earths, such as magnesium, yttrium and thorium, which have also been used in the Welsbach gas mantle. This form of lamp is known as the Nernst lamp, the utilization of rare earths in this manner having originated with Prof. Walther Nernst, a German scientist.

Q. 522—What is the form of the heated conductor?

A.—It is made up in small sticks, one of the standard sizes being $\frac{1}{40}$ inch in diameter and $\frac{31}{32}$ inch long. These are called "glowers." The glower of a Nernst lamp is a non-conductor when cold, and becomes a very poor conductor when hot.

Q. 523—If it is a non-conductor when cold, how does the current get through to heat it up?

A.—It doesn't. The glower must be warmed by some other means before it becomes sufficiently conductive to permit any current to pass. After current once starts through it, its temperature is increased to white heat and maintained there by the current.

Q. 524—How is the glower heated?

A.—Usually by a coil of fine wire imbedded in cement for protection from destruction, and located immediately adjacent to the

glower. The connections are as shown by Fig. 245. When the lamp is switched into circuit, current flows through the heating coil marked "heater," which immediately attains a high temperature and heats the glower. As soon as enough current passes through the glower to raise its temperature, the magnet *m* attracts its armature and thereby breaks the heater circuit, leaving the glower in operation.

Q. 525—What is the part marked *b?*

A.—This is a resistance in series with the glower, and commonly known as the "ballast."

Q. 526—What is it for?

A.—To prevent the glower from destroying itself by reducing

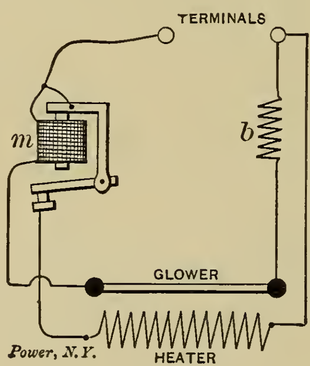

FIG. 245.

its resistance sufficiently to pass an excessive current. The hotter the glower becomes the lower its resistance.

Q. 527—How does the ballast resistance prevent the glower from reducing its resistance too far?

A.—The ballast has a high positive temperature coefficient; that is, its resistance increases rapidly with its temperature. Consequently a point is reached where an increase of current would increase the resistance of the ballast more than it would decrease the resistance of the glower, and under this condition no increase in current can occur.

Q. 528—Does the glower waste away like the carbons of an arc lamp?

A.—No. The material is not subject to oxidation or combustion. On a direct-current circuit the glower deteriorates rapidly from electrolytic action, a black deposit being made on the nega-

tive end, which gradually extends clear across to the positive end and renders the glower worthless.

Q. 529—Does the glower deteriorate on alternating current?

A.—Yes, slowly; there is of course no electrolytic action, the deterioration being mechanical, due to the intense heat.

Q. 530—How are Nernst lamps connected to the circuit?

A.—In parallel, exactly like incandescents.

Q. 531—How much power do they require?

A.—From $1\frac{1}{2}$ to 2 watts per candle-power.

FIG. 246.

Q. 532—Does the glower deteriorate in candle-power like the filament of an incandescent lamp?

A.—Yes, but not so rapidly. Most of the deterioration occurs just before the glower breaks. The lamp has not been in commercial service long enough at the time of writing to furnish reliable data as to candle-life.

Q. 533—In what form is the lamp made?

A.—Fig. 246 shows a single-glower lamp disassembled. They are also made with two, three, six and thirty glowers; in multiple-glower lamps the glowers are connected in parallel.

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